Gt. Britain.-ROYAL COMMISSION ON METROPOLITAN WATER SUPPLY.

REPORT

OF THE

ROYAL COMMISSION

APPOINTED TO INQUIRE INTO THE

WATER SUPPLY OF THE METROPOLIS.

Presented to both Houses of Parliament by Command of Her Majesty.

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ROYAL COMMISSION TO INQUIRE INTO THE WATER SUPPLY OF THE METROPOLIS.

VICTORIA R.

Victoria, by the Grace of God, of the United Kingdom of Great Britain and Ireland Queen, Defender of the Faith.

To Our right trusty and well-beloved Alexander Hugh, Baron Balfour of Burleigh; Our trusty and well-beloved Sir George Barclay Bruce, Knight, Civil Engineer; Our trusty and well-beloved Sir Archibald Geikie, Knight, Doctor of Laws, Professor of Geology and Mineralogy in Our University of Edinburgh; Our trusty and well-beloved James Dewar, Esquire, Master of Arts, Jacksonian Professor of Natural Experimental Philosophy in Our University of Cambridge; Our trusty and well-beloved George Henry Hill, Esquire, Civil Engineer; Our trusty and well-beloved James Mansergh, Esquire, Civil Engineer; and Our trusty and well-beloved William Ogle, Esquire, Doctor of Medicine, Fellow of the Royal College of Physicians, Greeting.

Whereas We have deemed it expedient that a Commission should forthwith issue to inquire whether, taking into consideration the growth of the population of the Metropolis and the districts within the limits of the Metropolitan Water Companies, and also the needs of the localities not supplied by any Metropolitan Company, but within the Watersheds of the Thames and the Lea, the present sources of supply of these Companies are adequate in quantity and quality, and, if inadequate, whether such supply as may be required can be obtained within the Watersheds referred to, having due regard to the claims of the districts outside the Metropolis but within those Watersheds, or will have to be obtained outside the Watersheds of the Thames and the Lea.

Now know ye, that We, reposing great trust and confidence in your knowledge and ability, have authorised and appointed and do by these presents authorise and appoint, you, the said Alexander Hugh, Baron Balfour of Burleigh; Sir George Barclay Bruce; Sir Archibald Geikie; James Dewar; George Henry Hill; James Mansergh; and William Ogle; to be Our Commissioners for the purposes of the said inquiry.

And for the better effecting the purposes of this Our Commission, We do by these presents give and grant unto you, or any three or more of you, full power to call before you such persons as you shall judge likely to afford you any information upon the subject of this Our Commission; and also to call for, have access to, and examine, all such books, documents, registers, and records, as may afford you the fullest information on the subject; and to inquire of and concerning the premises by all other lawful ways and means whatsoever.

And We do by these presents authorise and empower you, or any three or more of you, to visit and personally inspect such places as you may deem it expedient so to inspect for the more effectual carrying out of the purposes aforesaid; and to employ such persons as you may think fit to assist you in conducting any inquiry which you may hold.

And We do further by these presents will and ordain that this Our Commission shall continue in full force and virtue; and that you, Our said Commissioners, or any three or more of you, may from time to time proceed in the execution thereof, and of

every matter and thing therein contained, although the same be not continued from time to time by adjournment.

And We do further ordain that you, or any three or more of you, have liberty to report your proceedings under this Our Commission from time to time, if you shall judge it expedient so to do.

And Our further will and pleasure is, that you do, with as little delay as possible, report to Us, under your hands and seals, or under the hands and seals of any three or more of you, your opinion upon the matters herein submitted for your consideration.

Given at Our Court at St. James's, the fifteenth day of March, one thousand eight hundred and ninety-two, in the fifty-fifth year of Our Reign.

By Her Majesty's Command,
(Signed) HENRY MATTHEWS.

REPORT.

TO THE QUEEN'S MOST EXCELLENT MAJESTY.

MAY IT PLEASE YOUR MAJESTY,

WE, the Commissioners appointed by Your Majesty for the purpose of ascertaining whether the sources available within the watersheds of the Thames and Lea are adequate in quantity and quality for the water supply of the Metropolis, humbly report as follows:—

1. The Commission issued by Your Majesty, and dated the 15th day of March 1892, commanded us to ascertain, "Whether, taking into consideration the growth of the "population of the metropolis and the districts within the limits of the metro- "politan water companies, and also the needs of the localities not supplied by any "metropolitan company, but within the watersheds of the Thames and the Lea, "the present sources of supply of these companies are adequate in quantity and "quality, and, if inadequate, whether such supply as may be required can be obtained "within the watersheds referred to, having due regard to the claims of the districts "outside the Metropolis, but within those watersheds, or will have to be obtained "outside the watersheds of the Thames and the Lea."

PROCEDURE.

2. For the purpose of acquiring the information necessary to enable us to form a judgment upon the questions submitted to us, we placed ourselves without delay in communication with the metropolitan water companies, the Corporation of the City of London, the London County Council, and the councils of the counties of Bedford, Berks, Buckingham, Essex, Gloucester, Hants, Hertford, Kent, Middlesex, Oxford, Surrey, and Wilts. We also invited the Boards of Conservators of the Thames and Lea and all the urban and rural sanitary authorities whose districts are wholly or partially situated within the watersheds of those rivers, and all the water companies and public authorities which own waterworks in the same area to give us any information bearing on the subject of our inquiry which they might be in a position to afford.

By the metropolitan water companies and the Conservancy Boards we have been furnished with a very large amount of information, and from some of the other county councils, local sanitary authorities, and extra-metropolitan water companies we also received statements which proved to be of service. Mr. Dickinson, Deputy Chairman of the London County Council, and Lord Farrer attended at our sitting on June 27th, 1892, and handed in a statement on behalf of the Council, in which, after narrating some of the circumstances which led to the appointment of the Commission, the position of that body in regard to the inquiry is defined in the following words:—

"In order to assist the Royal Commission in their inquiry, the Committee have App. C. 16.
instructed their principal officers to summarise the results of their observations in their respective departments, and to lay these results before the Commission, and they have also arranged that other gentlemen who have made reports or otherwise informed the Council on the subject should be in readiness to lay before the Commission the results of their observations.

"The Committee have considered the above-mentioned reports, and in some instances have had them circulated to the Council, but these reports without further information are clearly not sufficient to enable the Council to form a judgment upon the various questions connected with the future water supply of London, and therefore the Council is anxious to avoid taking up any definite position either in favour of or antagonistic to the present methods of supply."

In fulfilment of these intentions, the Council has placed at our disposal, in the shape of reports and oral evidence of their principal officers, much valuable information.

3. A request was made to us on behalf of the metropolitan water companies and others that they might be represented by counsel at our sittings. To this request we did not see our way to accede, but as it appeared to us reasonable that, in a matter affecting large public and private interests, an opportunity of watching the progress of the inquiry should be given to persons materially concerned, we deemed it expedient to allow those connected with any of the companies and public bodies interested in the inquiry, and representatives of the press, to be present at all of our sittings at which evidence was taken. By grouping the subjects, and by providing that those taking opposite views should be heard on the same or immediately succeeding days, we have avoided the risk of injury to the material interests of those concerned.

4. From each witness who was about to be examined before us we obtained a written or printed statement, in as much detail as possible, of the matters upon which he was prepared to give evidence. All the statements so furnished that seemed to us to throw light on the subject of our inquiry, and were derived from the actual observation and knowledge of the persons tendering them, we have included among our appendices, and by this means have been enabled greatly to shorten the examination-in-chief of the witnesses, as well as to allow each to tell his own story in a concise and connected form. In some cases where tables of figures were included which we had obtained for ourselves, or which appear in another way, they have been omitted, for the sake of avoiding expense and of reducing the size of the volume.

5. We had under our consideration at an early stage of our proceedings the question whether it would be desirable that we should ourselves undertake any independent investigation, with scientific expert assistance, and we availed ourselves of the knowledge and experience of Sir George Buchanan, lately chief medical officer of the Local Government Board, who was good enough to discuss the question with us, at an interview on May 10th, 1892. After that interview it became known to us that such an investigation as that which we had been contemplating had been shortly before undertaken by some eminent scientific specialists under directions from the Royal Society, with the assistance of funds supplied by the London County Council, while other inquiries of a like nature were in progress at the instance of the metropolitan water companies, and we were informed that the results of all of them would be put before us by the persons by whom they had been conducted, provided that when they were completed it appeared likely that they would throw any light on the questions submitted to us.

App. E.

We therefore came to the conclusion that it was unnecessary for us to enter upon an independent inquiry into these subjects.

The promise made to us was subsequently fulfilled, and evidence on the points referred to was furnished to us by Dr. E. Frankland, Professor E. Ray Lankester, Professor W. R. Smith, Professor P. F. Frankland, Dr. Klein, and Dr. Sims Woodhead.

The Royal Society was likewise so good as to furnish us with copies of the report of the investigations conducted under their directions as mentioned above.

Major General Scott, the water examiner under the Metropolis Water Act, 1871, also showed every desire to help us in the course of our inquiry. He attended many of our sittings, and on February 15th gave evidence in regard to his duties and powers as water examiner, on the position of the metropolitan companies, with special reference to their subsidence reservoirs and filter beds, and also on the condition of the Thames and Lea.

6. We have sat on 45 days, of which 32 were occupied in hearing oral evidence. The witnesses examined have numbered 92, most of whom were put forward by the metropolitan water companies or the County Councils of London and the counties of Hertford, Middlesex, Surrey, Essex, and Buckingham, and by other public bodies in London and the neighbourhood. Some of the evidence produced to us was of such a character that we found that it could only be thoroughly investigated by the employment of an

Assistant Commissioner to visit the localities concerned, and ascertain for us upon the spot the precise facts. For this purpose, with the sanction of the Treasury, we appointed Mr. Reginald E. Middleton, M.Inst. C.E., whose services have been of great value to us, as well in conducting these local investigations as in examining the gauging arrangements at Teddington Weir, in carrying out independent gaugings of the River Thames at Sunbury and Molesey Weirs, and in estimating, with regard to the published returns of the quantities of water pumped by the water companies, what allowances should be made on account of slip of valves and short stroke of pumps.

7. For the purpose of answering the questions put to us in the reference, we divided our inquiry as far as possible into two divisions, the first of which comprised all the particular evidence as to the individual circumstances of the water companies at the present time, and the anticipations of the future which might be based upon them. Under this division, we took, first, the evidence of the metropolitan water companies as to the quantity of water which they were daily supplying per head of the population, the sources at their command to meet that supply at the present time, and the grounds upon which in their opinion future demands ought to be based; secondly, the evidence of the officers of the Conservators of the Rivers Thames and Lea as to the powers of the water companies to abstract water from those rivers, and the measures taken to prevent their pollution; thirdly, the evidence of officials in the employment of the London County Council, and of persons who had made investigations under the directions of the Council as to the amount of rainfall in the valleys of the Thames and Lea, the existing pollutions of those rivers, and the probable future requirements of the metropolitan area; fourthly, evidence prepared at the General Register Office as to the populations of the areas affected by our inquiry; fifthly, evidence offered by councils of counties and by corporations and local boards within the watersheds. Nearly the whole of this division of the evidence was taken before the end of July 1892, and our sittings since the month of October of that year have been mainly devoted to the second division of the evidence, which included the general evidence of engineers, geologists, chemists, and bacteriologists bearing upon the subject as a whole.

Areas affected by the Inquiry.

8. It seems desirable that we should define as accurately as is possible the areas which appear to us to be affected by the inquiry with which we are charged, and that we should mention the various water authorities by which at present such areas are supplied.

The administrative county of London extends over 121 square miles, and is co-extensive with the area called Registration London by the General Register Office, 3056.
except that the Hamlet of Penge, which is included in the county of London, is excluded from Registration London.

Greater London is the name given by the General Register Office to the area included within the Metropolitan and City Police districts. Such area includes all parishes wholly comprised within a circle of 15 miles radius from Charing Cross, and all other parishes of which any part is included within a circle of 12 miles radius from the same centre. Greater London thus not only includes the whole of the administrative county of London, but extends widely beyond it, and contains 3053.
an area of 701 square miles. In the evidence given before us the area within Greater London and outside the County of London has been called the Outer Ring, and it is within this area that at present the most rapid increase of population App. C. 16.
appears to be taking place.

The Water Companies included in the term Metropolitan Water Companies are eight in number, and the area over which collectively they have parliamentary powers of supply has been frequently termed Water London in the evidence given before App. C. 1.
us. This area, of which the boundaries bear no relation to those of any of the areas previously mentioned, includes the whole of the county of London and part 3054.
of the Outer Ring; but in the north and north-east, and again in the south-east and south-west, it extends beyond the limits of Greater London, stretching, in the case of the New River Company, to Ware in Hertfordshire, in the case of the East London Company, to Romford in Essex, in the case of the Kent Company, to Sundridge and Chevening in Kent, and, in the case of the Lambeth Company, to Esher in Surrey. "Water London" is the expression which we propose to use to describe this district, which comprises an area of about 620 square miles. 3086.

Water Companies.

See Map. **9.** The eight metropolitan companies are as follows:—

The New River Company,
The East London Company,
The Chelsea Company,
The West Middlesex Company,
The Grand Junction Company,
The Lambeth Company,
The Southwark and Vauxhall Company,
The Kent Company.

The districts supplied by the first five of these are on the north side of the River Thames, and those supplied by the last three on the south side.

The parliamentary districts of the metropolitan water companies in many cases overlap one another, so that two or more companies have powers of supply in one area. In almost all such cases, however, the companies have by private agreement settled their boundaries of actual supply in such a manner that only one of the companies is in any one place in occupation of the ground. (See Map.) In some few cases certain small areas are still supplied in common by two companies. Within the area of Greater London, and in some cases within the parliamentary districts of supply of the metropolitan companies, a number of private water companies and public authorities have powers of supply, and the area actually, supplied by the eight companies is, therefore, less than the area of their parliamentary districts. (See Map.)

The first question referred to us is whether the present sources of supply of the metropolitan companies as a whole are, having regard to the question of population, adequate in quantity and quality, but to enable us to consider and give an answer to this question, we must to some extent refer in the first place to the circumstances of the companies individually.

The New River Company.

App. A. 1. **10.** The New River Company was incorporated by royal charter in the reign of King James I., the charter prohibiting any interference with the New River, or the bringing to the cities of London and Westminster and the borough of Southwark water from any place whatsoever without the licence of the New River Company. The powers of the company have since been altered by Acts of Parliament passed at different times.

Their district of supply embraces the central part of the administrative county of London on the north side of the River Thames, including the whole of the city with the exception of a few supplies given by the East London Company in the parishes of St. Botolph, Bishopsgate, and St. Botolph, Aldgate. Outside the county of London the district of the company extends over the parishes of Edmonton, Enfield, Hornsey, and Tottenham in the county of Middlesex; but the sanitary authorities of Enfield and Tottenham have, as herein-after stated, independent sources of supply, and the company's operations are almost excluded from those parishes. In the county of Hertford the company's district extends over the parishes of Broxbourne, Cheshunt, Great and Little Amwell, Hoddesdon, Stansted St. Margaret, Ware, Wormley, and St. John's without the Borough of Hertford, but very few supplies are given by the company in these parishes. The average population supplied in 1891 was estimated by the company at 1,159,260 persons, and the average daily supply given during the same year was stated to be 33,028,779 gallons.

The East London Company.

App. A. 7. **11.** The East London Waterworks Company was established in the year 1808, and was authorised to purchase two existing waterworks—one being situated in Shadwell, and the other at West Ham—having had their origin in 1669 and 1747 respectively. In 1829 the company purchased the Hackney Waterworks and the Lea Bridge Mills, and obtained an Act to enable them to remove their intake from Old Ford to Lea Bridge.

In 1852 and 1858 the company's district was defined, and in 1867 an Act was passed enabling the company to add to their existing works, and to establish others, at Sunbury and Hanworth, for the supply of water from the Thames to their district, being then authorised to take from that river a quantity not exceeding 10,000,000 gallons a day.

The district of this company includes the following places and parishes in the administrative county of London, viz. :—

Whitechapel,	Stepney,
Mile End Old Town,	Poplar,
Mile End New Town,	Bethnal Green,
Spitalfields,	*Shoreditch,
*Bishopsgate,	Hackney,
Artillery Ground,	Old Ford,
*St. Botolph, Aldgate,	Homerton.
St. George-in-the-East,	Clapton,
Shadwell,	†Kingsland,
Limehouse,	†Shacklewell,
Wapping,	†Holloway,
Ratcliff,	Stamford Hill,
†St. Luke, Old Street,	†Dalston, and
†Stoke Newington,	So much of the parish of Woolwich as lies north of the Thames;
Bow,	
Bromley,	

the parish of Tottenham,* in the county of Middlesex; and the following places and parishes in the county of Essex, viz.:—

West Ham,	Stratford-le-Bow,
East Ham,	†Romford,
Low Leyton,	†Dagenham,
Leytonstone,	Wanstead,
Leyton,	Woodford,
Walthamstow,	Chigwell,
Waltham Abbey,	Loughton,
Waltham Holy Cross,	Chingford,
*Ilford,	Barking.

In the places marked * the company supply part of the parish only, and in the places marked † the company do not supply at all. The company state that the average daily quantity of water supplied in 1891 was 40,282,200 gallons, and the estimated population as stated by the Water Examiner, in his Report to the Local Government Board for the year 1891–92, was 1,158,500.

The Chelsea Company.

12. In the year 1723, by letters patent under the Great Seal, certain commissioners (who had been appointed by an Act passed in the previous year) were constituted and declared a body corporate under the name and title of "The Governor and Company of Chelsea Waterworks." In the year 1852 the company obtained a private Act of Parliament under which the above-mentioned letters patent and others subsequently granted, together with several previous private Acts, were repealed, and it was provided that the company, as from the date of the said letters patent (1723) should remain and continue incorporated, with perpetual succession, and a common seal, with power to maintain and construct waterworks, to supply water, and to hold lands and other property. The whole area supplied by the company is within the county of London. The average population supplied in 1891 was estimated by the company at 287,362 persons, to whom an average daily supply was given of 9,880,821 gallons. App. A. 13.

The West Middlesex Company.

13. The West Middlesex Waterworks Company was incorporated in 1806 by an Act of Parliament which empowered them to supply with water the parishes of St. Paul, Hammersmith; St. Mary Abbotts, Kensington; All Saints, Fulham; St. Nicholas, Chiswick; with other parishes at that time in the county of Middlesex, and also certain parishes in the county of Surrey. By a further Act in 1810 the limits of supply were extended. App. A. 12.

In 1866 another Act was passed extending the limits of the company's supply to the parishes of St. John Hampstead, Hendon, Willesden, and a small portion of Acton, all at that time in the county of Middlesex.

The company does not give any supply in that part of its district on the Surrey side of the Thames.

The average population supplied in 1891 was estimated by the company to be 577,235 persons, to whom an average daily supply of 16,906,906 gallons was stated to be given.

The Grand Junction Company.

App. A. 16. **14.** By an Act of Parliament passed in 1798 the Grand Junction Canal Company was empowered to lay pipes and supply water to the parish of Paddington and places adjacent. By an Act passed in 1811 these powers were transferred to a separate body, which adopted the name of "The Grand Junction Waterworks Company."

The limits for the supply of water by the company are defined by Acts of Parliament of 1811, 1826, 1852, 1861, and 1878, and include the following parishes and places:—

In the county of London—
- Paddington,
- Kensington,
- St. Marylebone,
- St. George, Hanover Square,
- St. James, Westminster,
- Hammersmith.

In the county of Middlesex—
- Brentford,
- Ealing,
- Chiswick,
- Acton,
- Hanwell,
- Isleworth,
- Twickenham,
- Teddington,
- Hampton,
- Hampton Wick,
- Hampton Court,
- Bushey Park,
- Whitton,
- Hanworth, and
- Heston.

The average population supplied in 1891 was estimated by the company at 350,000 persons, and the average daily supply given in that year was stated to be 18,750,000 gallons.

The Lambeth Company.

App. A. 21. **15.** The Lambeth Waterworks Company was incorporated by Act of Parliament in 1785. In 1848 the company was re-incorporated and empowered to supply water in the following parishes and places, viz.:—

In the county of London—
- Putney,
- Tooting Graveney,
- Clapham,
- Wandsworth,
- Battersea,
- Penge,
- Streatham,
- Newington,
- Bermondsey,
- Lambeth,
- Rotherhithe,
- Horseleydown,
- St. Saviour, Southwark,
- St. George the Martyr, Southwark,
- Christchurch, Southwark,
- St. Olave, Southwark,
- St. Thomas, Southwark,
- Lewisham, west of the Ravensbourne.

In the county of Surrey—
- Thames Ditton,
- Esher,
- Long Ditton,
- Kingston-upon-Thames,
- Malden,
- Morden,
- Wimbledon,
- Merton,
- Mitcham,
- Croydon,
- Beckenham, west of the Ravensbourne.

2580. It was stated in evidence that the area supplied by the company comprised 24·9 square miles in the town district, and 46·36 square miles in the extra-metropolitan district. In the year 1891 the population supplied was estimated by the company to be 655,921 persons, and the average daily supply was returned as 19,736,466 gallons.

The Southwark and Vauxhall Company.

16. The Vauxhall Water Company, which had been incorporated in 1805 under the name of the South London Waterworks Company, and the Southwark Water Company, which had been incorporated in 1835, were, by an Act of Parliament passed in 1846, amalgamated into one company under the name of the Southwark and Vauxhall Water Company. The company's area of supply was extended in 1884, and now includes— App. A. 18.

In the county of London
The Borough of Southwark, and the parishes of—
Bermondsey,
Rotherhithe,
St. Paul, and St. Nicholas, Deptford,
Camberwell,
Newington,
Lambeth,
Clapham,
Battersea,
Streatham,
Wandsworth, and
Putney.

In the county of Surrey—
Ham,
Petersham,
Kew,
East Sheen,
Sheen,
Roehampton,
Mortlake,
Barnes, and such parts of the parish of Wimbledon as are situate above the one hundred feet Ordnance contour line.

By the Act of 1884 above-mentioned, the urban sanitary authority of the Richmond district (now the borough of Richmond) were empowered at three days' notice to call upon the company for a supply in bulk not exceeding one million gallons a day. It was stated in evidence that the area of the company's district was 30 square miles. 2452. The average population supplied in the year 1891 was estimated by the company at 841,989 persons, to whom an average daily supply was given of 26,281,568 gallons.

The Kent Company.

17. The Kent Waterworks Company was incorporated by Act of Parliament in 1809, App. A 22. the authorized limits of supply being the two parishes of Deptford, the parishes of Greenwich, Lee, Lewisham, and Rotherhithe. In 1811 the limits were extended so as to include the parishes of Woolwich, Plumstead, Charlton, Bermondsey, Peckham, and Peckham Rye. In 1861 the company bought the freehold and plant of the Plumstead, Woolwich, and Charlton Pure Water Consumers' Company, which had been established in 1853, and in 1864 an Act was passed authorising the amalgamation of the North Kent Company, which had been established in 1860 to supply water to the parishes of Dartford, Crayford, Bexley, Wickham, Erith, Eltham, Chiselhurst, and Bromley. In 1867, 1877, and 1888 further additions were made to the district of the company, and at the present time its limits of supply extend over a total area of 179 square miles, of which about 30 are within the administrative county of London, 2841. and the remainder in the county of Kent. For the year 1891 they state their average daily supply at 13,534,000 gallons and the population which they believed themselves to be supplying at 460,524 persons.

POPULATION SUPPLIED.

18. Since the areas supplied by the companies are not co-extensive with any districts of which the populations are given by the Registrar-General in the census returns, no exact statement of the population is obtainable from official sources, and the companies have found it necessary to rely upon estimates compiled from such other sources of information as are at their command. Their usual method of procedure has been to ascertain from their books the number of their separate supply pipes, and assuming that each such pipe supplies one household, to multiply the number of households, so assumed, by a factor representing the probable average number of persons resident in one house. For such factor, recourse has been had to the census returns, from which has been ascertained the number of persons to a house in the metropolitan area, or in some other area deemed more comparable with the district of the particular company concerned.

The East London Company did not enter into any statement of the population supplied in 1891, but gave only the number of separate supplies furnished.

The populations estimated by the other companies may be shown as follows:—

New River	1,159,260
Chelsea	287,362
West Middlesex	577,235
Grand Junction	350,000
Lambeth	655,921
Southwark and Vauxhall	841,989
Kent	460,524
	4,332,291

Adding, in respect of the East London Company, the population for 1891, as stated in the report of the Local Government Board for 1891-92, page 248, viz., 1,158,500, the total population supplied by the water companies in 1891, as estimated by themselves, is found to be 5,490,791.

19. It soon became apparent from the evidence given to us that the number of separate supplies was not equivalent to the number of houses supplied and that the method of computation adopted was somewhat illusory. Moreover, on comparing the water companies' estimate of the population in their area of supply with the actual population in the area of Greater London, as taken for the census of 1891, it seemed to us probable that the water companies' estimate exceeded the true number. We therefore endeavoured to ascertain for ourselves, more accurately than had been hitherto done, the real number of persons supplied by the eight companies.

App. G. 2. For this purpose we obtained from each company a statement of the parishes supplied by it, either wholly or in part. Furnished with this information, the Registrar-General was so good as to have tables drawn up for us, showing the population by the census of 1891 of the parishes wholly supplied by one or more of the eight companies, within Registration London, and outside Registration London; the number of persons per supply in the parishes wholly supplied outside Registration London; and the population supplied in the remaining parishes, estimated on the assumption that the number of persons per supply in such parishes was the same as that in the parishes wholly supplied outside Registration London. The total population supplied by the water companies in 1891, ascertained in this manner, was 5,237,062 persons. The only source of error in this calculation that we are aware of is that here and there, within the area referred to, there are a few private sources of water still in use, and therefore, as the Census Returns of population have been taken as the basis of our calculation, the number of persons given may be slightly in excess of those actually supplied; but any error arising in this way must be infinitesimal as compared with the total number. It is not possible to ascertain exactly the number of persons obtaining water from private sources, and we must accept 5,237,062 persons as the closest approximation that can under the circumstances be made.

Water procured otherwise than from the Eight Metropolitan Companies.

20. Outside the parliamentary districts of the metropolitan companies, and wholly or partly within the area of Greater London, the following 10 water companies and *See map.* local authorities give supplies:—The Barnet District Gas and Water Company, the Central Middlesex Company (Alperton and Sudbury), the Colne Valley Company, the East Surrey Company, the Epsom Local Board, the Rickmansworth Company, the South West Suburban Company, the Sutton Company, the Uxbridge Local Board, and the West Surrey Company. All these companies and public bodies derive their supplies from wells sunk into the chalk formation, with the exception of the West Surrey Company, which has parliamentary authority to draw 3,000,000 gallons of water a day from the River Thames, and the South West Suburban Company, which in addition to a supply from wells, has authority to draw 1,000,000 gallons of water a day from the same river.

Within the area of Greater London, and also within, or partly within, the parliamentary districts of the metropolitan companies, the following six companies and public authorities give supplies:—The Cheshunt Local Board, the Croydon Corporation, the Enfield Local Board, the Richmond Corporation, the South Essex Company, and the Tottenham Local Board. These companies and public bodies also derive their water from wells sunk in the chalk formation, with the exception of the South Essex Company, which, in addition to its well supply, obtains water from

springs issuing from the chalk at Grays, in Essex, and the Richmond Corporation, which, in addition to its well supply, is entitled to take a supplementary quantity, if required, of 1,000,000 gallons a day from the Southwark and Vauxhall Company.

Outside the area of Greater London, and wholly or partly within the parliamentary districts of the metropolitan companies, the following three companies and local authorities give supplies:—The Hoddesdon Company and the Ware Local Board, which occupy parts of the district of the New River Company, and the Limpsfield and Oxted Company, part of whose district is included in that of the Kent Company. The water of these three undertakings is derived from wells sunk into the chalk formation.

21. We endeavoured to get information as to the quantity at present supplied by these extra-metropolitan companies and public bodies, but, from the fact that some were reluctant to disclose their affairs, others had only just commenced operations, and others again had not kept an accurate record of the water supplied, we were unable to make our information complete. It is, however, evident from the figures which some were good enough to furnish, that the total quantity given by all of them within greater London is not large, and, as it appears to us, cannot at the present time exceed an average of 10,000,000 gallons a day.

In the later portion of this report it is assumed that all the districts within the area considered will receive their supplies out of the quantity found to be obtainable from the various sources there mentioned, irrespective of any other sources now under contribution.

Future Area of Supply and Population.

22. When we turn to the consideration of future requirements, the first question that presents itself for discussion is what area ought to be taken into account. It is manifest that neither Registration London, nor the London of the County Council, nor even Water London—that is, the area within which the eight great London water companies have certain parliamentary rights and duties—is sufficiently extensive for our purpose. These several areas have been gradually built over and the vacant space for new dwellings has been so much reduced that the population has been for years extending into the surrounding zone of suburban districts, which have thus become, if not technically, yet, to all intents and purposes, integral parts of London itself. These suburban districts must clearly be included in our area, and even such more remote districts must be taken in as may reasonably be expected to be reached by the spreading of London population at no very distant period.

After due consideration, we do not think it would be satisfactory to take any smaller area as our basis than the City and Metropolitan Police Districts, or, in other words, what is conveniently known as Greater London. This covers 701 square miles, and for our present purpose may be described as the area contained in a circle drawn round Charing Cross as a centre, with a radius of 15 miles. To this area we have further to add certain parts of Water London which lie outside Greater London. As, however, the addition of these outlying districts would give an area not recognised in the official statistics, and would therefore complicate the estimate of population, we will omit them for the present, and take them into the account later on.

23. The following table shows what has been the population of Greater London at each of the last six enumerations, and what has been its rate of increase in each of the five intercensal periods:—

Population of Greater London.

Census of—	Population.	Increase per Cent. in the previous Decennium.
1841 - - -	2,235,344	—
1851 - - -	2,680,735	19·9
1861 - - -	3,222,720	20·2
1871 - - -	3,885,641	20·6
1881 - - -	4,766,661	22·7
1891 - - -	5,633,332	18·2

The rate of growth, as shown in the last column of this table, has been far from equable. It increased with each successive decennium up to 1881, and then suddenly fell to a lower point than in any previous 10 years in the table.

24. If, instead of confining our view to separate decennia, we take longer periods into consideration, we obtain the rates given in the following table, which shows in a convenient form the increase of the population of Greater London in periods of various lengths:—

Number of Years.	Period.	Total Increase per Cent. in Period.	Average Annual Increase per Cent. in Whole Period.
50	1841–91 - - - -	152·0	1·86580
40	1851–91 - - - -	110·1	1·87387
30	1861–91 - - - -	74·8	1·87902
20	1871–91 - - - -	45·0	1·87442
10	1881–91 - - - -	18·2	1·68458

Such, then, are the facts as to the past growth of the population of Greater London. What inference are we to draw from them as to its probable growth in the future? The ill-success of those who, in times past,* have ventured to make more or less confident forecasts of future population warns us to abstain from any confident prediction, and we see some difficulty in assuming that the population will continue to grow in the future in the same ratio as it has been found to grow in the past. In attempting to make any such calculation we are at once face to face with the difficulty of deciding what period of time we are to take as representing the past. Are we to take the growth of 10, 20, 30, or of how many years as our basis of estimate? Fair arguments may be found for each or any selection. On behalf of the longer periods it may be urged that their length diminishes the disturbing influence of casual fluctuation, and therefore makes them the safer basis for calculation; while on behalf of the shorter periods, and especially on behalf of the shortest of all, it may be said that their rates of growth represent the new conditions to which the population is exposed—when space is getting filled up and practically unlimited expansion is no longer possible—and that these therefore are the best guides for the immediate future; while, lastly, it may be argued that all these periods alike should be discarded, and that we should assume that the same causes which led to a marked diminution in the rate of growth in the last as compared with the next preceding decennium, of which causes doubtlessly the fuller occupation of space was one of the most important, will continue to operate, with ever increasing force, in the future; and that, consequently, we ought to calculate on the supposition that the rate of growth will continue to fall, decennium after decennium, in as great a proportion as it fell in 1881–91, as compared with 1871–81.

25. This argument is certainly not without weight. Nevertheless, we do not think the tendency of the rate of increase to diminish has as yet been shown for a sufficiently long period to justify us in adopting it as the basis of our estimate; and, after weighing all the various arguments, we think that it will be safer for us to assume that the most recent rate of growth in the past, namely, that of the last decennium, will be maintained in the future; that is to say, that the population will continue to increase at the rate of 18·2 per cent. decennially, or in the ratio of 1·68458 per cent. annually. We are, of course, fully aware that this is nothing more than an assumption. But some assumption or other must necessarily be made, and, of the several that are possible, this seems to us less open to challenge than any other. We have, moreover, the satisfaction of knowing that, should we have made an erroneous selection in choosing a basis for estimate of future population, each successive census will give an opportunity of revision.

Assuming this, then, to be the future rate of increase, the population of Greater London at each of the four next decennial enumerations, will be as shown in the first column of the following table; the other columns have been added only to show, in a

* For instance, Sir William Petty, writing in 1682, thus confidently expresses himself: "Wherefore it is "certain and necessary that the growth of the city (*of London*) must stop before the year 1840, and will be "at its utmost height in the next preceding period, A.D. 1800, when the number of the city will be eight "times its present number, viz., 5,359,000. And when (besides the said number) there will be 4,466,000 "to perform the tillage, pasturage, and other rural works necessary to be done without the said city."—*Essay on the Growth of the City of London.*

form convenient for those who may desire it for purposes of comparison, what the population would be, if any of the other rates of increase we have mentioned were to be adopted as the basis of the calculation.

Future Population of Greater London. App. G. 1. Table IV.

Middle of Year.	If the Average Rate of Increase equal the Average Rate in the Period mentioned at the Head of each Column.					If the Rate of Growth continues to diminish in the same Proportion as it did in 1881–91, as compared with 1871–81.
	1881–91.	1871–91.	1861–91.	1851–91.	1841–91.	
	Column 1.	Column 2.	Column 3.	Column 4.	Column 5.	Column 6.
1891	5,656,909	5,659,548	5,659,611	5,659,540	5,659,428	5,652,556
1901	6,685,445	6,814,486	6,817,642	6,814,108	6,808,583	6,477,831
1911	7,900,987	8,205,110	8,212,620	8,204,214	8,191,076	7,235,737
1921	9,337,542	9,879,519	9,893,032	9,877,905	9,854,284	7,915,895
1931	11,035,289	11,895,622	11,917,277	11,893,036	11,855,210	8,509,590

26. To the population of Greater London we have now to make a further addition for the outlying parts of Water London, of which mention was made previously. These outlying parts, which have an area of 92,313 acres, or about 144 square miles, contained in 1881 a population of 63,543 persons, while in 1891 the number had increased to 76,041, showing a growth of 19·7 per cent. in the decennium. Assuming that this rate of growth will be maintained without change in the future, the population of these outlying districts will be increased at the end of succeeding decades as shown in the following table:— Par. 22.

Middle of 1901	- -	91,407
„ 1911	- -	109,385
„ 1921	- -	130,899
„ 1931	- -	156,645

App. G. 3.

27. The next point we have to decide is how far ahead we are to look in interpreting the term "future" in the question referred to us for consideration. We have been invited by a representative of the London County Council, acting under instructions from the Water Committee of that body, to look forward for at least 50 years, on the ground that, should the London County Council hereafter become the water authority, the necessary capital expenditure would have to be spread over a period of 60 years. These, however, are considerations that lie completely outside the reference to us, and putting them therefore aside, we cannot but think that the suggested period is unnecessarily long, especially when it is remembered that every addition to the period adds enormously to the chances of serious error in the computation of probable future population. App. C. 16. 4635.

We believe that 40 years form the longest prospective period that it is usual to consider in questions of water supply, and, though some of us are inclined to think that even a term of 40 years is longer than is necessary, we have come to the conclusion that it will be safer for us to adopt that term in our forecast, reckoning from the year of the last enumeration. Adding to the 11,035,289 presumed inhabitants of Greater London in 1931 the 156,645 persons shown opposite that year in the last table, we arrive at an aggregate population in 1931 of 11,191,934, or, in round numbers, of $11\frac{1}{4}$ millions, in the area of which the water requirements have to be considered, viz., 845 square miles.

The main question, then, to which we have to find an answer stands now as follows: Can a sufficient supply of water of sufficiently good quality be obtained from the Thames and Lea Valleys for the use of $11\frac{1}{4}$ million persons without serious prejudice to the other inhabitants of those valleys?

Population in Basins of Thames and Lea.

28. The Registrar-General has taken out for us from the Census Returns from 1861 to 1891, the number of persons living within the watersheds of the Rivers Thames and Lea, above the intakes of the metropolitan water companies. The number of persons within the watershed of the River Thames above Molesey is stated to be 1,056,415, having increased from 816,814 since the year 1861. The number within the watershed of the Lea above Chingford is stated to be 189,287, App. G. 1. Tables V. and VI.

having increased from 142,085 in the same period. In the remoter parts the population shows no tendency to rapid increase, and has in some cases declined. The rate of growth, as might be anticipated, is greatest in those parts nearest to the metropolis, and in those urban communities which are situated on or near the two rivers and their larger tributaries.

WATER NOW SUPPLIED.

29. The yearly and monthly daily average quantity of water returned to the Water Examiner under the Metropolis Water Act, 1871, as supplied by the eight metropolitan companies in the year 1891, is shown in the following table:—

YEARLY and MONTHLY DAILY AVERAGE SUPPLY by each of the EIGHT METROPOLITAN WATER COMPANIES during the Year 1891.

Month.	New River.	East London.	Chelsea.	West Middlesex.	Grand Junction.	Lambeth.	Southwark and Vauxhall.	Kent.	Totals.	Month.
	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	
January - -	35,004,500	51,659,047	9,475,229	16,960,499	16,800,506	22,148,871	25,338,253	15,353,449	192,740,354	January.
February - -	31,008,000	46,826,360	9,399,680	16,263,666	17,465,734	20,272,918	25,485,504	13,769,384	180,491,255	February.
March - -	30,287,000	43,355,914	9,351,607	16,197,377	17,672,179	18,840,671	24,870,738	12,780,832	173,356,318	March.
April - -	30,994,000	42,892,358	9,355,234	16,480,260	17,923,532	18,461,643	25,146,820	13,019,679	174,273,526	April.
May - - -	32,928,000	43,669,585	10,245,378	17,323,261	18,473,773	18,709,360	25,409,173	13,150,319	179,908,849	May.
June - -	34,573,000	45,201,329	10,691,276	18,308,522	19,995,761	20,487,482	27,111,575	14,145,706	190,514,651	June.
July - - -	36,897,000	44,618,741	10,838,290	18,209,238	20,444,486	21,408,864	27,191,727	14,006,728	193,615,074	July.
August - -	34,165,000	44,687,007	10,020,700	16,686,401	18,744,043	20,221,274	28,001,063	13,444,803	185,970,296	August.
September - -	34,646,000	45,464,745	10,169,297	16,815,685	18,259,308	20,788,068	28,[illegible],834	13,701,240	188,148,177	September.
October - -	32,585,000	42,803,536	9,683,135	17,016,264	18,635,582	19,266,033	26,727,227	13,252,154	179,968,931	October.
November -	31,230,000	41,594,362	9,723,008	16,361,113	18,362,391	17,984,008	25,327,008	12,463,405	173,045,295	November.
December -	31,386,000	43,830,785	9,383,605	16,307,961	18,490,778	18,260,808	26,465,901	13,324,295	177,450,133	December.
12	395,703,500	536,603,778	118,336 439	202,930,247	221,268,073	236,850,000	315,378,828	162,411,994	2,189,482,859	12
Daily Average -	32,975,292	44,716,981	9,861,370	16,910,854	18,439,006	19,737,500	26,281,569	13,534,333	182,456,905	

30. The figures furnished to us by the water companies for the purposes of our inquiry will be seen to differ in some cases to a small extent from these. But the difference is explained as arising from some of these very large figures having been put into round numbers, and from the fact that an attempt was made in the case of some of the companies to correct the errors which undoubtedly occur in the returns made by them to the Water Examiner. We need not, however, allude further to these discrepancies, since neither the figures returned to the Water Examiner nor those furnished to us gave with absolute accuracy the quantities of water really delivered by the companies into their mains. The quantities of water pumped are calculated from the number of strokes made by the engines taken in connexion with the capacity of the pumps. Such calculations are vitiated by the unavoidable want of perfect tightness in the pump valves, and by the failure of the non-rotary engines employed to maintain a uniform length of stroke.

In making up their returns for the Water Examiner, the several water companies have differed in their practice with regard to the allowance which should be made for these circumstances. In the case of the East London, Chelsea, West Middlesex, Grand Junction, Southwark and Vauxhall, and Kent Companies, no deductions from the gross calculation have been made. In the case of the other companies certain deductions have been made, differing in the case of each company, and settled by reference to their special circumstances. In addition to these sources of error, the water used for the condensers of the engines and for washing the sand removed from the filters is taken by the companies from their mains, and after being used is run to waste. For the purpose of calculating the quantity pumped to their districts for consumption, the amount so used should be deducted.

31. It appeared to us necessary, for the purposes of our inquiry, that we should, if possible, obtain more exact information as to the quantity of water supplied by the companies. We, therefore, charged our Assistant Commissioner to investigate the
App. H. 5. question, and the result of his Report, the whole of which is included in our Appendix, is given in the following table. In this table, column 2 shows the gross supply for

the whole year of 52 weeks, calculated from pump displacement as above described, column 3 shows the quantity which our Assistant Commissioner, after investigation, reports, was actually delivered into the companies' mains during the same time, column 4 shows the average supply per diem as stated by each company, and column 5 shows the actual average supply per diem as ascertained by our Assistant Commissioner.

1. Name of Company.	2. Gross Supply per Annum, calculated from pump displacement.	3. Net Supply per Annum.	4. Supply per Diem as stated by Company.	5. Net Supply per Diem.
	Gallons.	Gallons.	Gallons.	Gallons.
1. New River - - -	12,211,488,675	11,881,315,050	33,028,779	32,640,976
2. East London - - -	16,536,018,280	14,452,474,780	44,758,000*	39,704,601
3. Chelsea - - - -	3,621,353,237	3,478,889,470	9,937,560*	9,557,388
4. West Middlesex - -	6,847,697,565	5,612,846,438	16,906,906*	15,419,907
5. Grand Junction - -	6,998,830,724	6,079,431,386	18,750,000*	16,701,734
6. Lambeth - - -	7,671,977,190	7,365,379,860	19,736,466	20,234,560
7. Southwark and Vauxhall -	10,051,427,523	8,871,898,815	26,281,568*	24,373,348
8. Kent - - - -	4,963,631,791	4,561,237,306	13,534,618*	12,530,871
	68,402,424,985	62,303,473,105	182,933,897	171,163,385

* Without allowance for slip and short stroke.

Consumption per Head of Population.

32. The quantity of water consumed per head of the population differs widely in the districts of the several companies. Taking the population estimated by them as being actually supplied, we find that the quantities consumed per head per day are as shown in the annexed table, ranging from 26·71 gallons in the case of the West Middlesex Company, to 47·72 gallons in the case of the Grand Junction Company; the average over the whole of the population supplied being 31·19 gallons per head per day for the estimated population. App. H. 5.

The calculation by which this result is obtained is shown in the following table :—

Name of Company.	1. Net Supply per Diem.	2. Population.	3. Net Supply per Head.	
	Gallons.		Gallons.	
1. New River - -	32,640,976	1,159,260	28·16	45
2. East London - -	39,704,601	1,158,500	34·27	98
3. Chelsea - - -	9,557,388	287,362	33·25	24
4. West Middlesex - -	15,419,907	577,235	26·71	43
5. Grand Junction - -	16,701,734	350,000	47·72	75
6. Lambeth - - -	20,234,560	655,921	30·85	53
7. Southwark and Vauxhall -	24,373,348	841,989	28·94	77
8. Kent - - -	12,530,871	460,524	27·21	58
	171,163,385	5,490,791	31·19	

Of this quantity, an average proportion of about 20 per cent., or a little over six gallons per head, is estimated as being used for trade and public purposes. It therefore follows, if this estimate is correct, that about 25 gallons is the average daily supply per head of the population now given by the water companies for domestic purposes.

The very large amount supplied by the Grand Junction Company per head of the population of their district attracted our attention, and we made it a subject of inquiry. When Mr. Fraser, the engineer of the Company, was before us, he explained it by saying that his Company found it cheaper to pump water than to supervise and control the waste of water supplied. 2231.

Average daily Supply.

33. It has, however, been shown above that the populations estimated by the several companies are probably in excess of those really supplied, and it has been mentioned that an independent estimate, made for us at the General Register Office, gives 5,237,062 persons as the total population supplied by the eight companies in 1891.

If we adopt this calculation and apply it to the figures of net supply per diem in 1891, as stated in column I of the table in the preceding paragraph, we arrive at an average consumption for trade and domestic purposes taken together of 32·68 gallons per head per day.

34. Since the system of constant service was first introduced in 1873, the proportion of the total supply brought under it has been yearly increasing. It will be seen, however, from the following table, which shows the proportion of each company's supply given upon this system at the end of the year 1891, that the several companies have proceeded at very different rates in their adoption of it.

21st Annual Report of the Local Government Board, p. 236.

Percentage of Total Supplies given on the System of Constant Service by each Metropolitan Water Company at December 31st, 1891.

New River	45 per cent.
East London	98 ,,
Chelsea	24 ,,
West Middlesex	43 ,,
Grand Junction	75 ,,
Lambeth	53 ,,
Southwark and Vauxhall	77 ,,
Kent	58 ,,

The particulars of this system do not greatly concern the questions with which we have here to deal, except in so far as they may effect any increase or decrease of waste.

General Geological Structure of the Basins of the Thames and Lea.

35. As a preliminary to an examination of the nature and capabilities of the several sources which we are considering, it is necessary to form a clear conception of the geological structure of the two river basins, and of the relation of that structure to the question of water-supply. This subject was so fully treated in the Report of the Duke of Richmond's Commission of 1869, that it will not be needful to repeat here the details so well put forward in that volume. Since the publication of that report, however, much new information has been gathered respecting the superficial deposits which so materially affect the descent of water underground. We shall therefore call attention to the nature and distribution of these deposits with especial reference to the object of the present inquiry.

At the outset we would allude to the great importance of distinguishing between the older formations which descend to depths of sometimes many hundreds of feet below the surface, and the superficial layers of sand, gravel, loam, and other materials which are merely spread irregularly over the surface, and in this part of the country seldom exceed a few yards in thickness, but which, as they conceal the rocks below, and more or less interfere with the access of water to them from above, are of great importance in regard to the question of water-supply.

In most geological maps it is only possible, on account of the smallness of their scale, to delineate the older formations, and the superficial deposits are consequently omitted. The Geological Survey of the United Kingdom, however, now carefully traces the varying nature and extent of the surface accumulations. A copy of the Geological Survey Map of the basins of the Thames and Lea on the scale of one inch to a mile has been prepared for us, and has been largely made use of in the course of our inquiry. We have also been much assisted by the statements and evidence given by Messrs. Whitaker and Topley, two officers of the Survey.

The older rocks within the region embraced in the reference to us may be grouped in three great series. 1st. The Jurassic formations. 2nd. The Cretaceous formations. 3rd. The Tertiary formations. The second and third of these series are found both in the basin of the Thames and Lea. The first occurs in the Thames basin only.

Basin of the Thames.

36. Taking first the basin of the Thames, we may conveniently consider it as divisible into three parts, each of which coincides with the area of one of the groups of formations just mentioned. In the highest portion the river draws its sources from and flows over a series of Jurassic strata. At Abingdon it enters upon the second portion of its basin and runs across the Cretaceous system as far as Windsor. Below that point its course lies across the Tertiary formations, although in the Gravesend district the Cretaceous rocks once more rise to the surface.

The superficial deposits are much more irregularly distributed. Their most continuous portions lie in the bottoms of the valleys, where they appear as alluvial gravel, sand, loam, and brick-earth. The alluvial plains of the Thames are in some places several miles broad. Sheets and detached patches of various "drifts" are found scattered over the surface of the older formations, even up to the tops of the watersheds. Some of these superficial coverings, especially to the north, where "boulder-clay" occurs, are tolerably impervious, so that water runs off them without at once sinking into the rocks underneath. Others are more mixed in character, consisting of materials partly permeable, partly more or less impermeable, while a third kind may be regarded as easily pervious, allowing the rain to sink readily through them.

In estimating the relative capacities of different areas for absorbing the rainfall it is desirable to keep in view not only the nature of the older formations in regard to the percolation of water through them, but also the extent to which they are covered with a layer of pervious or impervious superficial deposits.

37. For the purposes of this inquiry it will be of advantage to consider the portion of the Thames basin above the intakes of the water companies separately from the rest. Taking that portion by itself and computing the respective areas of the three geological systems in it we find that of the total area of 3,548 square miles, 1,322 square miles App. 41.
lie on Jurassic rocks, 1,420 on Cretaceous, and 806 in Tertiary.

Each of these geological systems has its own distinctive characters in regard to the passage of water through its component strata. Some of the rocks exposed at the surface are readily permeable by rain water, others are practically impermeable, while a third group are of intermediate nature. Thus, in the Jurassic part of the basin, an area of 537 square miles is occupied by pervious strata, 616 by impervious, and 169 by those of intermediate kind. The pervious strata consist of limestones, calcareous sandstones, and other materials which, being full of joints and fissures, afford a ready passage for the water. The impervious materials are beds or thick masses of clay such as the Kimeridge clay and Oxford clay. These materials alternate with each other in successive sheets, and the effect of this arrangement is to allow the water to flow through and accumulate in the pervious bands until arrested by the impervious layers, when it issues in springs along the junction of the two kinds of rock.

38. The chief water-bearing formations in this upper part of the basin are the Great Oolite group and the Inferior Oolite. So great is the capacity of these rocks for water, that the larger springs which they supply continue to flow even through seasons of drought. No satisfactory evidence has been laid before the Commission as to the obtaining of any additional supply of water for London by sinking wells in the Jurassic portion of the Thames basin. It is evident, indeed, that any supply thus 8943–86.
obtained would probably be at the expense of the springs, and would be practically only so much abstracted from the river above the present intakes of the companies. The same remark applies to the proposal to impound the springs that rise from the Jurassic rocks. A more feasible scheme is that which deals with the construction of reservoirs to intercept and store the water of some of the upper tributaries of the Thames. But, as elsewhere remarked in this Report, the geological structure of the ground makes it questionable whether suitable sites for the construction of such reservoirs could be found among formations so porous as most of those in the Jurassic system. We thus arrive at the conclusion that according to our present information, no addition to the present water supply of London is to be obtained by any operations conducted in the upper or Jurassic part of the Thames basin.

39. Below Abingdon, the Thames enters upon the Cretaceous system, and continues to flow thereon as far as Windsor. The rocks which constitute this system within the Thames basin consist of a lower group of sandy strata (Upper and Lower Greensand), with an impermeable bed of clay (Gault). The Lower Greensand is an important water-bearing stratum in certain districts, but though about 450 feet thick at Reigate, it thins

out northward under London. The upper group of Cretaceous rocks consists of earthy limestones and marls, the uppermost member of which is the white Chalk. This latter formation is by far the most important source of water-supply in the south of England. It ranges up to about 800 feet in thickness and is divisible into successive zones, all of which are more or less water-bearing, though it is mainly the upper chalk which must be relied upon as a source of water-supply. Valuable evidence has been laid before us as to the structure of the Chalk, its floors of flint, joints, fissures, and other features which affect the flow of water through it.

Considered with reference to their capacity for absorbing water from the surface, the rocks of the Cretaceous system which are pervious occupy 1,243 square miles in the Thames basin, and the impervious cover 177 square miles. There are some among them of sufficient importance to be singled out of intermediate character. The sands and porous limestones form an easily permeable series, while the Gault clay and a few other beds are impermeable.

40. The Tertiary formations within the Thames basin may be conveniently considered to consist of three main groups. A lower group of permeable sands and gravels (Thanet Sand), a thick central clay from 400 to 500 feet thick (London Clay), and an upper thin and scattered group of sands and gravels (Bagshot Sands). The Thanet Sand at the base is a water-bearing formation, and to the south of London yields a certain amount of water, but it cannot be reckoned upon as available for a large supply in the Thames basin. The London Clay is an impermeable mass of material which prevents water from passing through it to feed the pervious rocks beneath it, and also from ascending to the surface in springs. The Bagshot Sands absorb water and throw it out at their junction with the impervious London Clay below, but they occupy too small an area to be worthy of serious consideration, except for mere local supplies.

With reference to hydrology, the Tertiary formations, which cover 806 square miles in the Thames basin above the intakes, may be grouped in three divisions, whereof pervious strata cover 161 square miles, impervious 366, and those of mixed character 279.

41. It will be kept in view, however, that in the foregoing estimates of the respective areas of pervious, impervious, and intermediate rocks in the Thames basin, regard has been had only to the water-capacity of the several members of the Jurassic, Cretaceous, and Tertiary systems, without reference to whether or not they lie at the surface. The superficial deposits are scattered so irregularly over the older formations that it is difficult to make satisfactory estimates of their respective areas, except upon the basis of detailed surveys. But these surveys have been completed for only a portion of the district in question. So far as available they will be made use of in this Report in considering the nature of the surface of the Chalk areas in the basins of the Thames and Lea.

Basin of the Lea.

42. The basin of the Lea resembles that of the Thames below Abingdon, but with this important difference that its sources rise within the Chalk and Tertiary districts, and are not increased by the influx of water from any older group of rocks, and with this further distinction that the Cretaceous area of the basin lies on the chalk and does not include the outcrop of any of the older members of the Cretaceous system.

App. C. 41. The total area of the Lea basin is computed by Mr. Topley at 542 square miles. But we need only deal with the portion above Feilde's Weir, an area of 422 square miles, which includes, practically, all the drainage that supplies the water companies. The distribution of the chalk and superficial deposits in this latter area is given in paragraph 121.

It should be remarked, however, that both in the impervious and mixed ground in this basin the drainage on the surface flows towards the chalk. It was brought out clearly in evidence that, where this arrangement holds, the water which runs off an impervious covering of clay to bare chalk may be largely or wholly absorbed by the latter, so that in comparing the capacity of two chalk areas for absorbing water we require not only to take note of the respective areas of impervious materials, but how these materials are arranged. If in the one case the rain which falls on the impervious cover is at once conducted into the chalk the presence of that cover may, in great part, be disregarded; if in the other case, the ground slopes away from the chalk the water which falls on the

impervious cover is prevented from reaching the chalk, and the area of this cover should be deducted from the area of absorption of the chalk.

The area of Tertiary ground included within the basin of the Lea lies almost wholly below Feilde's Weir. Except for local supplies derived from lower tertiary strata, and more especially from the drift gravels and sands scattered over the London clay, this Tertiary area hardly requires notice as a water-bearing district.

43. As the Upper Chalk is so porous a formation and absorbs so large a proportion of the rain which falls upon its surface, advantage is taken of its water-bearing capacity to sink deep wells into it. In the valley of the Lea and in the valley of the Thames east of the companies' intakes large quantities are obtained in this way. The relation of the chalk to water-supply, and the possibility of obtaining largely increased quantities of water from this formation are dealt with in the section of this report treating of future supplies. As the present and, probably, the future supply of water to London depend so largely upon the capabilities of the chalk as a water-bearing rock, we shall recur to the subject in a later part of the Report.

PRESENT SOURCES OF SUPPLY.

44. We now turn to the discussion of the present sources from which the water supplied by the eight metropolitan companies is derived. These sources are four in number, namely, (1) the Rivers Thames and the Lea; (2) gravel beds adjoining the main stream of the Thames, and other gravel beds at Hanworth; (3) natural springs, and, lastly, (4) wells sunk into the chalk or other strata at such points in the watersheds as may have been selected, and it will probably be convenient that we should discuss these in the order in which they have just been named.

45. All the companies, except the Kent Company, are dependent for some part of their supply upon water derived either from the Thames or the Lea. The supply of the New River Company from the River Lea is regulated by the River Lea Water Act of 1855, under which a quantity of about 5,400,000 gallons daily is reserved for the navigation, and as much as may be necessary in addition to keep up the head of water in each level of the river. The New River and East London Companies are empowered *pari passu* to take all the remaining flow of the stream. The intake of the New River Company is situated upon the River Lea, between Hertford and Ware locks. The navigation of the river does not extend above Hertford. At the intake is a gauge capable of passing 22,500,000 gallons a day, and it is the practice of the company to limit to this quantity its draught from the Lea. App. A. 1.

46. The supply of the East London Company from the River Lea is regulated, as in the case of the New River Company, by the River Lea Water Act, 1855. By that Act, after the navigation water previously mentioned has been reserved, the New River and East London Companies have equal rights with regard to the remaining flow of the river; but while the New River Company restricts its daily take from this source to 22,500,000 gallons, the East London Company abstracts a daily average supply of about 33,000,000 gallons, and in dry seasons is taking the whole flow of the river, except so much as is required for navigation. In practice, the Conservancy do not take their statutory quantity, but usually pass down for navigation purposes, instead of 5,400,000 gallons, not much more than 1,500,000 gallons, and at the most 2,500,000 gallons per diem. The intakes of the East London Company upon the River Lea are at Enfield Lock and Ponder's End. In addition to this supply the East London Company is entitled under its Act of 1867 to take 10,000,000 gallons a day from the River Thames, and for this purpose their intake is in the reach above Sunbury Lock. App. A. 7. 18 & 19 Vict. c. 196. App. B. 17. 597–9. 1185–93. 1230–3. 1477–86. 30 & 31 Vict. c. 148.

47. The remaining five companies, the Chelsea, the Grand Junction, the West Middlesex, the Lambeth, and the Southwark and Vauxhall, derive the main portion of their supplies from the Thames. The intakes of the West Middlesex, the Grand Junction, and the Southwark and Vauxhall Companies are at Hampton, on the north side of the river. The intakes of the Chelsea and Lambeth Companies are at West Molesey, on the opposite side. All these intakes are on the reach of the river between Sunbury and Molesey Locks, that is in the reach of the river next below that from which the East London Company derives such quantity as it may require out of its authorised take of 10,000,000 gallons.

48. For the purpose of thoroughly understanding the respective positions of these companies in regard to their supplies it is necessary to touch briefly upon the history of their connexion with the river since 1852. In that year the Act known as the Metropolis Water Act, 1852, was passed. By this Act it was provided that none of the companies should, after August 1st, 1855, take any water from the Thames below Teddington Lock. In 1848 the Lambeth Company had applied for powers to take water at Long Ditton, and the Corporation of London, who were the Conservators of the river, opposed it, and ultimately secured, amongst other conditions, an undertaking from the company that they would not abstract more than 20,000,000 gallons a day. In 1852 the four other companies applied for powers similar to those obtained by the Lambeth Company, and the Corporation took the same course as in 1848. The result was, that each of these companies bound themselves in a separate agreement not to take more from the river than 20,000,000 gallons daily.

15 & 16 Vict. c. 84.

App. B. 2.

In the year 1857 the jurisdiction of the Corporation as Conservators of the river was transferred by Parliament to the present Conservancy Board, in whom was vested the rights of the Corporation under those agreements. In the year 1866 the jurisdiction of the river above Staines was also transferred to the Conservancy, and each of the companies became bound to pay a sum of 1,000*l.* a year to this Board, the agreements as to the quantities to be taken being left subsisting as before. In the same year the West Middlesex Company had a bill before Parliament, and on the application of the Conservators, a clause was inserted confirming the limit of 20,000,000 gallons imposed by the agreements. Similar steps were taken in the case of the Chelsea Company in 1875. There is, therefore, this distinction between the cases of the East London, the West Middlesex, and the Chelsea Companies, on the one hand, and the cases of the Grand Junction, the Lambeth, and the Southwark and Vauxhall Companies on the other; that the three first-named are subjected to a statutory limit of the quantity they may abstract from the Thames, while others are limited only by agreement with the Corporation of the City, when acting as Conservators, and recently with the present Board.

29 Vict. c. 6. s. 8.

38 & 39 Vict. c. 108. s. 25.

App. B. 1. **49.** The history of the financial arrangements between the companies and the Conservancy will be found set forth at length in the statement furnished to us by the latter. It is sufficient for our present purpose to note that prior to 1886 the companies were under obligation, partly by Act of Parliament and partly by agreement, to pay 13,450*l.* a year for the privilege of taking water from the river. In 1886 the companies agreed to pay a further sum of 4,500*l.*, so that the total amount now paid by them is 17,950*l.* a year. In respect of this additional sum of 4,500*l.*, the Conservators agreed to allow the companies to draw 20,000,000 gallons daily in excess of the amounts allowed to each company under the agreements of 1852. This amount of 20,000,000 gallons was allocated among them as follows:—

Chelsea - - -	- 2,000,000	gallons.
West Middlesex - -	- 4,500,000	,,
Grand Junction - -	- 4,500,000	,,
Lambeth - -	- 4,500,000	,,
Southwark and Vauxhall	- 4,500,000	,,
	20,000,000	,,

3252. 3275–3307. 1669–75. Our attention was called to the fact that under this arrangement the Chelsea Company, though limited by its Act of 1875 to 20,000,000 gallons, considers itself to have acquired a right to take 22,000,000 daily, and similarly the West Middlesex considers itself to have acquired a right to take 24,500,000 gallons daily instead of 20,000,000. The contention of the Conservators is that, by an Act of Parliament passed in 1878, they are given a power of allocation as between the companies of the water which they may respectively draw from the river; and as the companies other than those two and the East London Company are limited only by agreement with the Corporation of London, to whose interest the present Board have succeeded, they are now acting strictly within their legal powers in making the arrangement which has just been described. The matter was made the subject of an arbitration in the year 1888, when the auditor appointed by the Local Government Board raised a question as to the legality of the payment then made for the first time under these agreements. The arbitrator decided in favour of the legality of the agreements,

and it is not within our province to express any opinion upon that decision; but we think it right to take notice of it, and to call attention to it, in view of the suggestion made to us in the course of our inquiry as to the possibility of taking a much larger supply of water from the Thames, with which suggestion we shall deal in a later portion of our report.

50. Assuming, for our present purpose, the legality of these agreements, the following table shows the quantity of water which each of the five companies can now draw from the Thames:—

Chelsea - - -	22,000,000	gallons.
West Middlesex - - -	24,500,000	„
Grand Junction - -	24,500,000	„
Lambeth - - -	24,500,000	„
Southwark and Vauxhall -	24,500,000	„
	120,000,000	„

The addition of the 10,000,000 gallons a day allowed to the East London Company makes up the 130,000,000 gallons which is the total volume authorised to be drawn from the Thames at the present time by the metropolitan companies for the supply of London.

51. The Lambeth Company, on the south side of the river, and the Grand Junction and Southwark and Vauxhall on the north side, obtain considerable supplies from gravel beds on lands in close proximity to the river, which they have acquired under their parliamentary powers, and the East London Company derive a supplementary supply from gravel beds in immediate proximity to their pumping station at Hanworth.

The Lambeth Company, in the statement which they submitted to us, said that, App. A. 21.
"During the construction of the reservoirs" at West Molesey "a very large volume of sub-soil water contained in the deep gravel bed overlying the London clay had to be encountered. This water being rain, naturally filtered and of great purity, was utilised by means of a double series of glazed stoneware pipes, 12 to 24 inches in diameter, perforated with small holes, and laid along the river sides of the reservoirs, extending inland at the ends and between them, to conduct the water to the 2480.
engine wells. This supply, to the extent of 7,000,000 or 8,000,000 gallons per day, is used to replenish the store in the reservoirs during floods, when the river intake is entirely closed."

The manager of the company, Mr. Louttit, was asked whether this supply was put 2483.
forward as in addition to the 24,500,000 gallons which the company are entitled to take from the river. He replied in the affirmative, and in support of the contention quoted section 5 of the Lambeth Waterworks Act, 1883, which is in the following terms:—"The company may, in addition to any lands they are authorised to acquire and hold under the powers of their existing Acts or this Act, from time to time 2484.
by agreement acquire in fee either by purchase, exchange, or otherwise, any land not exceeding in the whole 20 acres; and the company on such land may sink wells or shafts, and may within the limits for the supply of water by the company supply water therefrom, and make, lay down, and maintain tanks, engines, conduits, mains, and pipes, and may use such lands for the general purposes and convenience of their undertaking; provided that the powers by this Act conferred for the acquisition of land, shall not be exercised in any part of the water limits of the company and proprietors of the Kent Waterworks." It is undoubtedly the fact that the pipes which take this water are laid within 20 feet of the bed of the river. Being asked for further information as to the direction in which this water seems to be naturally going, whether towards the river or in a direction parallel 2498.
to the main stream, Mr. Louttit replied: "I think all the gravel beds to the extent of several miles are perfectly saturated with water coming down from the direction of the Bagshot Sands;" and he added, "the whole of these gravel beds contain vast volumes of water." In support of this opinion, he referred to the inquiry into the question of this underground water which was conducted by Mr. J. T. Harrison and Col. Hildyard in connexion with the Lower Thames Valley Joint Board Sewerage Scheme in 1880, and said that it was then proved that the water flows in a north-easterly direction, that is to say, from the south-west, and comes through these gravel beds in very large quantities. Mr. Louttit further contended that these gravel beds 2503.

afford a very valuable adjunct to the supply of his company, and said that in eight days, during the severe frost of the winter 1890–91, the company pumped no less an amount than 54,740,000 gallons out of them.

52. In the statement supplied to us by the Grand Junction Company, it was set out that the intakes from the river were arranged for the inflow of water direct from the stream into the pump-wells, but the company possessed, in addition, a complete system of works for natural filtration of the Thames water which had been in use for more than 10 years, by means of which the river water was passed through extensive beds of gravel and sand characteristic of the neighbourhood, and was then pumped into the reservoirs, from which it passed to the ordinary filters; and that the company had lately acquired other similar land adjoining the river at Sunbury which they were preparing to utilise in the same manner—the quantity of water so treated being, of course, included in the authorised take of the Company.

53. Mr. Restler, the Engineer of the Southwark and Vauxhall Works, explained to us, by means of a diagram, a similar system adopted by his Company for the filtration through natural gravel beds of water turned into them artificially from the Thames. He further stated that a considerable volume of water was found in the gravel independently of this artificial charging, and that from this source 3,000,000 gallons a day could be procured; and he contended that this quantity ought not be counted as part of the 24½ millions a day his Company is empowered to abstract from the Thames.

54. Mr. Hack, the engineer of the Chelsea Company, told us he was now making
2004. experiments with a view of taking underground water, or as he called it, "infiltration" water at Molesey, in the same way as the Southwark and Vauxhall and Grand Junction Companies have been doing for some time past. In his case he finds the water in the gravel standing at the level of the water in the stream; and being asked, "then practically it is water which if you did not take it in that way would find its way into the stream and go down"? He replied, "Yes, we do not pretend that it is
2009. anything but filtered water; it is a rough filter that I am making really. But
2016–23. there is a mixture, I may tell you, and a large mixture, of land water that is purely spring water."

55. The gravel beds belonging to the Grand Junction and Southwark and Vauxhall Companies are contiguous to one another; and immediately to the west side of them, that is higher up the river, the land belonging to a private owner has been recently opened out for building purposes; and these companies have found it necessary, as a
2182. matter of precaution, to build a puddle wall of clay about 4 feet in thickness, extending from the surface of the ground completely through the gravel beds down to the London clay. Our views upon these gravel beds will be found in paragraphs 89 to 91.

56. The pumping works of the East London Company for their Thames supply are situated at Hanworth, about two miles from the river. It was found in the course of their construction that the gravel beds overlying the London clay at that point were saturated with water, and the company determined to pump therefrom as an
711. additional source of supply. In the year 1891 they derived an average of about
714. 1,200,000 gallons a day from this source, and stated that it had been available to them for about three years. They do not appear to take the water continuously, but their
716. engineer told us that they do so "intermittently, depending partly upon the state of the Thames," and added that the maximum amount they had ever taken would be about 2,000,000 gallons a day for a month or two months together; "if we are pumping a large quantity from the Thames, we do not take as much from these
718–9. underground springs." He stated to us that, at the point at which they pump, the water sometimes lies within 4 or 5 feet of the surface of the ground, and that its level is 13 feet higher than the level of the Thames at Sunbury, the collecting pipes from which the water is taken being laid 40 feet below the surface. It seems
722. that at this point the surface of the London clay is very uneven and is covered with a bed of light clean gravel, from 20 to 26 feet thick. This water is drained from a
759–61. large area upon which there is at the present time a very sparse population, and the evidence put before us goes to show that at the present time it is a safe and legitimate

source of supply; but we cannot regard it as in any sense to be relied on permanently, in respect that its continuance must be dependent upon the district not being opened 729.
out for building purposes.

57. The only perfectly natural spring which at the present time is used by any of 60.
the metropolitan companies is the Chadwell spring, belonging to the New River Company. This spring rises in the parish of Amwell, near Hertford. Its flow is 66.
said to range, under different circumstances, from a maximum of about 4,000,000 165.
gallons to something less than 500,000 gallons per day, and the whole of it is taken by the company. The continuous series of gaugings of its flow for a long period was App. A. 3.
put before us. It has averaged over 4,000,000 gallons a day for a year, but during 5380.
the five months of August, September, October, November, and December, 1890, it fell in some cases to a daily average for a week of 720,000 gallons, and in only one week in the last six months of that year did it average above 3,000,000 gallons a day. Its flow is said to answer to, and to diminish very quickly in, periods of drought; and in the autumn of 1891, for a period of four weeks it yielded less than 5383.
500,000 gallons daily. 169.

58. The last source of supply with which we have to deal is that from deep wells. The supply of the Kent Company is exclusively derived from wells sunk into the 2776–8.
chalk and greensand within an area described by themselves as consisting of 179 square miles of which only 30 square miles are within the administrative county of London, the remainder being in the county of Kent. 2767.

59. In the case of the New River Company, whatever quantity is needed beyond the 80.
22,500,000 gallons taken from the River Lea and the amount derived from the Chadwell spring to make up their daily supply has to be pumped from wells. The average daily quantity taken by this company from wells in 1891 was stated to us to be about 66.
8,500,000 gallons, and the wells in use were described to us as follows:—

Broadmead well, above Ware. App. A. 1. 79.

Amwell End well, at Ware.

Amwell Hill well, below Ware.

Amwell Marsh well, between Ware and St. Margarets.

Rye Common well, at St. Margarets.

Hoddesdon well, Broxbourne well, Turnford well, between Broxbourne and Cheshunt.

Cheshunt well, Hoe Lane well, above Enfield.

Highfield well, at Edmonton.

Campsbourne well, at Hornsey.

Betstile well, at New Southgate.

This company also has deep wells at Hampstead Heath, Hampstead Road, and Bush Hill Park, Edmonton, which have been acquired from other companies whose undertakings they have purchased; these wells, however, have no machinery for pumping. The evidence of the engineer of the company goes to show that, whilst 88–9.
pumping from the Cheshunt well temporarily lowers the water level in the Turnford well, and, similarly, pumping at Amwell Hill affects the Amwell Marsh well, in no other case, so far as his observations go, does the abstraction of water from one well affect the supply obtainable from any other.

The supply from the wells of the Kent Company is in all cases pumped directly into the service reservoirs and used without filtration. This is also done in the case of the Betstile and Campsbourne wells of the New River Company; but the water from all the other wells and from the Chadwell spring is passed into the New River, and is filtered before distribution.

60. The East London Company have recently resorted to wells with considerable 648.
lengths of headings or tunnels in the chalk of the Lea Valley to supplement their supply. Such wells as they have sunk were described to us as not being in full operation during 773–83.
the year 1891, and the total quantity drawn from them was not more than a daily average of about 1,750,000 gallons. In their case, while the water from the Hanworth gravel beds was filtered before distribution, all the water they took from wells was pumped direct to the service reservoirs. A detailed description of the wells of this company will be found in the evidence given by Mr. Bryan, their engineer.

In addition to the sources of supply which have now been mentioned, the New River Company obtains from ponds at Hampstead and Highgate a quantity of about 300,000 gallons a day; but this is used only for watering streets and for other non-domestic purposes.

61. All the companies which supply river water have, besides their service reservoirs, others which are used for purposes of storage and subsidence. The importance of this is now universally acknowledged, and considerable additions have been made to the resources of most of the companies in this respect during recent years. All these
12,937. companies have also filter-beds, through which the water derived from the rivers and from gravel-beds is passed prior to its delivery into the mains which carry it to the consumers. The following table, which has been compiled and was put before us by General Scott, shows how the companies are situated respectively in regard to these important departments of their operations.

1892.

Names of Companies.	Capacity of Subsidence Reservoirs.		Filters.		Thickness of sand in Filters.		Monthly Rate of Filtration per Square Foot per Hour, 1891.	
	Cubic Contents.	Number of Days' Supply.	Area.	Area per Million Gallons of Average Daily Supply.	Maximum.	Minimum.	Mean Monthly Averages.	Maximum Monthly Averages.
	Galls.		Acres.	Acres.	Ft. ins.	Ft. ins.	Galls.	Galls.
New River - -	169,000,000	5·1	16½	0·50	2 3	1 5	2·08	2·30
East London - -	615,000,000	13·7	29¼	0·67	2 0	1 4	1·33	1·33
Chelsea - -	140,000,000	14·2	6¾	0·68	4 6	3 6	1·75	1·75
West Middlesex -	117,500,000	7·0	14	0·88	3 3	2 6	1·25	1·33
Grand Junction -	64,500,000	3·5	17¾*	0·96*	2 0	1 3	1·99	2·25
Lambeth - -	128,000,000	6·5	9½	0·48	3 0	2 6	2·15	2·36
Southwark and Vauxhall.	46,000,000	1·8	14½	0·55	3 0	1 6	1·5	3·50

* This is represented as including six acres of natural sand and gravel used for preliminary filtration, which is succeeded by filtration through washed sand and gravel.

Estimates of Future Requirements.

62. Having thus far dealt with the past history and present conditions and circumstances of the existing water companies, and with the areas and population of the districts to be supplied, we now proceed to discuss the necessities of the future, and in this connexion we will set out first the views of the several companies. As in the presentation of the case these bodies have been working together, it is not surprising that they have all adopted the same term, viz., 40 years, as the period for which it is desirable now to look forward and have endeavoured to demonstrate their ability to provide an adequate supply of water for the growing population up to the end of that term. We have already intimated that we are in accord with the companies as to the forecast period it is necessary to deal with.

The following table gives the figures laid before us by each company as to the population and requirements of its district in 1931:—

——	Estimated Population in 1931.	Estimated daily Supply per head in 1931.	Supply required per day.	Supply available per day.
New River - - - -	1,658,000	28·5	47,250,000	*56,500,000
East London - -	1,697,000	33·0	56,000,000	66,000,000
Chelsea - - - - -	375,000	35·0	13,125,000	22,000,000
West Middlesex - - -	959,187	28·0	26,857,236	24,500,000
Grand Junction - - -	584,969	42·0	24,500,000	24,500,000
Lambeth - - -	1,136,441	25·0	28,411,025	30,500,000
Southwark and Vauxhall -	1,215,457	25·0	30,386,425	41,000,000
Kent - - - -	900,000	30·0	27,000,000	29,000,000
Total - -	8,526,054	29·73	253,529,686	294,000,000

* Deducting 330,000 gallons of unfiltered water from Hampstead Ponds.

63. The first point to be noted in this table is that the companies, as a whole, assume that in the future the supply to be given per head is to be smaller than it has been in the past. Thus, taking the total estimated population in 1931, as made out from the forecasts of each of the companies, viz., 8,526,054 and dividing it into the total daily quantity to be furnished, viz., 253,529,686 gallons, we get the daily supply per head as 29·73 gallons as compared with 31·19 gallons, the average daily supply in 1891, as shown by the table in paragraph 32. But, as has been already pointed out, the 31·19 is subject to correction if we assume, as we propose to do, that the population supplied by the companies in 1891 was 5,237,062 and not 5,490,791 as they had estimated. This correction increases the quantity per head by 1·49 gallons, thus bringing it up to 32·68.

In order to compare the quantity suggested by each company as likely to be sufficient in the future, as contrasted with what they were giving in 1891, we must add the 1·49 to each of the figures in the third column of the table in paragraph 32, with the following results, viz.:—

——	Corrected Quantity in 1891.	Suggested future Quantity.	Decrease.	Increase.
New River	29·65	28·50	1·15	
East London	35·76	33·00	2·76	
Chelsea	34·74	35·00		·26
West Middlesex	28·20	28·00	·20	
Grand Junction	49·21	42·00	7·21	
Lambeth	32·34	25·00	7·34	
Southwark and Vauxhall	30·43	25·00	5·43	
Kent	28·70	30·00		1·30

The notable reductions are thus seen to be in the cases of the Lambeth, Grand Junction, and Southwark Companies, and the justification for them is based upon the experience that has been gained in stopping waste by means of systematic day and night inspection, facilitated by the use of Deacon's or other self-recording meter, and followed up by the immediate repair or renewal of bad fittings. Upon these points we 358, 420,
have taken the evidence of the engineers and managers of the respective companies, 2160, 2454,
and also that of Mr. Thomas Hawksley and Sir Frederick Bramwell, who have had 2521.
large experience on this particular question, and we have had the advantage of the views put forward by Mr. Baldwin Latham, Mr. Birch, Mr. Binnie the engineer of the London County Council, and others.

64. Speaking on behalf of the East London Company, Sir Frederick Bramwell stated 979.
that from 25 to 27 gallons ought to suffice for all purposes in that district, on the assumption that six or seven gallons are used for trade, and in his statement he said App. C. 29.
that he saw no reason why the average daily quantity throughout the metropolis should not be reduced to 20 gallons for domestic purposes, making, with six gallons for trade, 26 gallons as the average daily total. Mr. Hawksley, in his evidence given on the 7150.
seventeenth day, stated that, judging by his very extensive experience, 20 gallons were sufficient for domestic consumption and ordinary trade uses, but that to be quite safe he increased that figure here to 25 gallons. These gentlemen hold the opinion, therefore, that the companies' suggestion as to the future requirement (on the average, 29·73 gallons), is at least 4 gallons in excess of what is necessary.

65. Mr. Baldwin Latham's evidence on this point was as follows:—

(*Q.*) "What number of gallons should be estimated per head for domestic supply 7524-5.
and for all other purposes?—(*A.*) I have taken it at 5 cubic feet, 31¼ gallons. * *
* * For domestic supply I do not suppose it is possible to use more than 15 gallons, 7527.
with proper means for the prevention of waste. * * * * I know in many 7529.
cases what the consumption is, but I have not made a general estimate in that way.

I have taken my own house for example. I have had it metered for some years to ascertain what the consumption should be. It is more than an ordinary house, 15 to 16 people ordinarily residing in it, and the use of baths is common; then the water also has been used in the summer time for watering gardens, and it does not come to
7531. 22 gallons per head per day on the average of three years. * * * * My estimate of 31¼ gallons is quite a safe one."

881-2. **66.** Mr. Bryan, the engineer of the East London Company, is not hopeful of reducing the consumption for all purposes in his district below 33 gallons, owing to the reckless way in which the classes which constitute the large majority of his company's customers waste the water. A staff of over 30 inspectors constantly employed (and
886-9. authorised to releather taps without charge) is incompetent to prevent this waste, because it is not mainly due to defective fittings but to the fact that taps are deliberately left running for hours and sometimes for days together.

3152. **67.** On this question Mr. Binnie, the engineer of the London County Council, has given us the consumption in a number of the cities of continental Europe and of America, all using far more water per head than is usual in this country, and has named also Dublin, Glasgow, and Edinburgh, where 47, 50, and 40 gallons respectively are said to be supplied. He states that London is now far behind continental cities in the use of water for ornamental, sanitary, and cleansing purposes, and quotes Paris as consuming 18 gallons per head in this way. Foreshadowing in the future, under the auspices of the County Council, a more lavish consumption in this respect than at present, Mr. Binnie is of opinion that 35 gallons is the least quantity that should be estimated per head per day for all purposes, and he would prefer, in fact, to make it 40.

2437. **68.** Some of the company's officers are of opinion that if they were empowered by
2598–2602. Parliament to exercise fuller control than they now can over the material and make
2814. of the fittings the consumption might be reduced. It is in great measure due to the possession of such powers that the low figures named by Mr. Hawksley have been arrived at in the large towns of the Midlands and North of England. If the London companies, or any authority upon which hereafter may devolve the duty of supplying London with water, were entrusted with similar powers, there is, in our opinion, little doubt that considerable reduction in consumption could be made.

It is questionable, however, if with a meter consumption for trade and public purposes of six gallons per head the quantity used for all purposes in London will be kept down to 25 or 26 gallons in the future.

There is a tendency in all flourishing towns to introduce into dwelling-houses of lower and lower rental every year appliances such as waterclosets, fixed baths, and hot-water apparatus, which inevitably conduce to the increased use of water.

69. After considering the whole of the evidence given on this point by the water companies' officers, the independent experts, and the engineer of the County Council, and bringing to bear the general experience of some of our number, we have adopted 35 gallons as a safe basis of calculation for the future daily requirement per head of the population of Greater London. This figure is 5·27 gallons higher than the average future provision suggested by the eight companies, but only 2·32 more than the quantity they have actually been giving, and we are inclined to think that if it errs at all it is on the side of lavishness.

70. Applying this figure to the 11,191,934 people we have assumed may occupy Greater London and the outlying parts of Water London in 1931, we get as the daily requirement 391,717,690 gallons. Some addition must, however, be made to this quantity to provide for an increased demand in very dry hot weather, and in times of severe frost, and we put this at 6 per cent., as being the excess of the highest daily average for a month in 1891 over the daily average for the whole year. Abnormal excesses of consumption for shorter periods may be disregarded, as they can be provided for from storage. Adding then 6 per cent. to the 391,717,690 we get the maximum daily provision required in 1931 as 415,219,752 gallons.

71. As compared with this, the combined companies' forecast of requirement in 1931 is 253,529,686 gallons a day, and their anticipated capability of supply at that date is 296,357,236 gallons, made up as follows :—

——	Gallons.	Gallons.
NEW RIVER.		
Authorised take from River Lea	22,500,000	
Chadwell spring and wells	34,000,000	
		56,500,000
EAST LONDON.		
From River Lea with storage reservoirs	30,000,000	
Authorised take from River Thames	10,000,000	
Gravel beds at Hanworth	2,000,000	
Existing wells in Lea Valley	11,000,000	
Further wells in ditto	13,000,000	
		66,000,000
CHELSEA.		
Authorised take from River Thames	- - - - -	22,000,000
WEST MIDDLESEX.		
Authorised take from River Thames	24,500,000	
From the Thames, chalk wells, or gravel beds	2,357,236	
		26,857,236
GRAND JUNCTION.		
Authorised take from River Thames	- - - - -	24,500,000
LAMBETH.		
Authorised take from River Thames	24,500,000	
Gravel beds	6,000,000	
		30,500,000
SOUTHWARK AND VAUXHALL.		
Authorised take from River Thames	24,500,000	
Gravel beds, Hampton	3,000,000	
Existing Streatham well	3,000,000	
Seven proposed wells at 1,500,000 gallons a day each	10,500,000	
		41,000,000
KENT.		
Wells on present stations and lands	- - - - -	29,000,000
		296,357,236

From the companies' point of view, there was manifestly no necessity to show that they would be, in a position in 1931 to provide more than the above quantity, as it is nearly 17 per cent. in excess of the demand anticipated by them at that date. It should, however, be stated that the representatives of all the companies who dealt with these figures expressed the opinion that either by means of storage of the Thames and Lea waters, from the chalk or from valley gravel beds, additional water in large volume might be obtained, if required. The specific figures above quoted must not be taken, therefore, as representing, in the opinion of the several companies, the measure of their capability of supply.

SUGGESTIONS OF THE COMPANIES.

72. The suggestions made by the water companies for extending their works, and so augmenting the volume of distributable water, may be stated in order as follows :—

(1.) The abstraction of more water from the Thames without providing storage.
(2.) The abstraction of more water from the Thames and Lea with provision for storage.
(3.) The abstraction of water from gravel beds adjoining the Thames.
(4.) The abstraction of more water from deep wells in the chalk formation.

(1.)

73. Upon the first of these points Mr. R. W. Peregrine Birch, C.E., gave evidence to the following effect, viz. :—That in the exceptionally dry summer season of 1887 the average daily flow of the Thames for a fortnight at the companies' intakes at Hampton and Molesey had fallen to 281 million gallons, a quantity which he stated might fairly be described 7471–7

as the least fortnightly quantity hitherto recorded, and the least that may ever be reasonably expected. At that time the companies were abstracting 101 million gallons, leaving 180 millions to pass down the river to the next lock, which is at Molesey. For navigation purposes there, 5 million gallons a day may be required, and Mr. Birch contends that the remaining 175 millions might, without doing any harm, have been
App. C. 30. taken out by the companies, making a total abstraction of 276 million gallons. To this quantity he adds 84 millions as easily obtainable from the River Lea and chalk wells, making with the 276, 360 millions as available at the very height of an abnormal drought. At 35 gallons this would be a supply for 10,285,714 persons.

App. C. 31. **74.** Mr. Baldwin Latham, in his printed statement, says: "Both the Thames and the Lea are navigable channels, and the waters are ponded up to sufficient depths for the purposes of navigation. The absolute flow of water down a navigable river is of no importance so far as navigation is concerned, so long as there is sufficient depth of water for navigation, and a quantity flowing sufficient for the purpose of lockage."

Again: "If it became requisite therefore that an additional supply of water should be taken from the Thames to that which is now authorised by the companies, no evil consequences could arise to the river itself, and there would always be an ample supply of water below the intakes of the companies to supply the necessary lockage, and in the tidal part of the river the absence of fresh water would immediately be made up by the entrance of an additional volume of sea water."

Sir Frederick Bramwell, dealing only with seven companies (excluding the Kent), expressed his views as to the source from which the increasing demands for water
App. C. 29. in the future are to be met, in the following terms:—"It appears to me there would be, in fact, no objection to the simplest of all practical solutions of the difficulty, namely, the allowing the companies to draw the needed greater supplies from the River Thames. I believe that a further 50,000,000 gallons a day might well be allowed." This would bring the quantity up to 180 millions a day.

2838–46. In the course of examination, the late Mr. Henry J. Marten, C.E., who appeared for the Thames Conservators, expressed the opinion that 200 million gallons a day might
7273–90. safely be taken from the Thames without storage, and Mr. Hawksley assented to this view.

According to Mr. Birch, therefore, over 100 million gallons a day may be obtained direct from the Thames, supplemented by the Lea and chalk wells, more than the companies anticipate will be required in 1931. Again, adding to Messrs. Hawksley and Marten's 200 millions from the Thames only the present take from the Lea and wells, we get a quantity exceeding the companies' expected 1931 demand.

12,284–5. Mr. More, the engineer of the Thames Conservancy, speaking for himself and his Board, stated also that 200 million gallons a day might be abstracted by the companies without producing any harmful effect upon the river down to the new weir at
12,286. Richmond. That below that point the reduction in depth and volume of the ebb
12,308–16. stream would interfere with navigation for a couple of miles or so, but that otherwise no injury would be done. He further stated that the partial depletion of the stream
12,288–9. might be made up by the storing of 50 million gallons of the water of each rising tide (100 millions per day) in a reservoir to be constructed in the Richmond Deer Park,
App. B. 16. this quantity to be let out again during the last four or five hours of the ebb. If this were done, 200 million gallons a day, that is, about double the quantity now taken, might be abstracted, without any harm whatever being done to the river in any part of its course.

75. It is important that the true import of the evidence taken on this matter should be distinctly appreciated, as, if reliable, it goes to show that the fears vaguely held by the public that the river is already being injuriously depleted by the companies are without foundation. It was abundantly proved at the inquiries which were made by Committees of both Houses of Parliament in the Session of 1890 upon the Richmond Weir and Footbridge Bill, that the shallowness of the river at Richmond, Twickenham, and up to Teddington Lock was due almost entirely to works of improvement which had, through a course of years, been going on lower down, beginning with the removal of Old London Bridge in 1832. The many wide piers of that bridge acted as a weir and held up the water several feet. In later times, Blackfriars and Westminster Bridges were rebuilt, with the effect of further improving the waterway, and many shoals, especially above Westminster, were dredged away, the net result of all these operations being

to depress the low water line at Richmond about 4 feet. The depression due to the water companies' present draught amounts to only a small fraction of this, and it is desirable that the effect of any further abstraction should be ascertained and distinctly explained.

76. The facts then are these—The intakes of all the companies, except that of the East London, are located in the reach of the river, between the Sunbury and Molesey locks, and the water is held up in that reach at a practically constant height (except in flood times), by the weir at its lower end, that is, at Molesey. Whether 100 million gallons a day or 200 millions were being drawn out by the companies, no difference in the appearance of the river in respect of its fulness could be appreciated. In the latter case the speed of the flow of the stream below the intake would, of course, be less than in the former, because a smaller quantity of water would be passing through the same sectional area in the same time, but in both cases the speed would be sufficient to prevent mischief. It must be remembered that we are now discussing a condition of things which occurs only at intervals of many years and for but a week or two at a time, and when the water coming down would be quite clear and free from suspended matter. On most other occasions it would not be of the slightest importance whether the companies were abstracting 100, 200, or more million gallons a day.

Down to Molesey weir, then, it is manifest no harm would be done by taking 200 millions.

We then come to the reach between Molesey and Teddington locks, which is 4¼ miles in length. The conditions in this stretch are similar to those above Molesey, with this difference, that the Mole and Hogs Mill rivers add their waters to those of the main stream, and thus increase its volume and velocity above Teddington. In this reach, therefore, no harm can be done.

77. As everybody is aware, Teddington is at the head of the tidal range, and the lock and weir there are at present the lowest upon the Thames, and therefore below it another state of things has to be dealt with, because the water is not held up to
a constant height, but rises and falls with the tide. Now it is admitted on all hands 7273,
that the diminution of upland water coming down the stream would have no practical 7486,
effect upon the level of high water at Teddington, which would be determined solely 8249.
by the action of the tidal wave. On the other hand, such diminution of upland water 12,855.
would be appreciable at the latter end of the ebb, when all the water pushed up by the impulse of the tide had receded and only the land water was coming down. Below Teddington and down as far as 300 yards below the railway bridge over the Thames at Richmond, however, no evil would result from this after another year, because at that point a new removable weir is being constructed, which will operate in maintaining the depth of water above it, as the fixed weirs do at Teddington and Molesey. The trouble resulting from additional abstraction. if any, would commence then below this weir, and what this would be, and how simply it could be remedied has already been explained by reference to Mr. More's evidence.

Mr. Binnie stated his objections to this scheme in the following words :— App. C. 7.

"The engineer is not of opinion that any good would result to the river by impounding tidal water, as has been proposed, at the Old Deer Park, below Richmond, as this would only be tidal water and not the comparatively pure flow of the Thames from its upper reaches which he considers so important for the purity of the river.

"The state to which a river is reduced, where dependent entirely upon tidal action in its course through a thickly populated district, may be observed in the lower reaches of the River Lea where the upland waters have been abstracted by the water companies instead of being permitted to flow down and purify the tidal portion.

"The engineer is of opinion that if water is abstracted from the Thames or Lea, a proper amount of compensation water should be permitted to flow down the long reach of the river between Staines and Teddington, a distance of 18 to 20 miles, and afterwards into the tidal portion of the river below Teddington Weir."

When under examination upon the same subject, Mr. Binnie admitted in answer to questions, that the difference between the present circumstances and those which would
exist, supposing Mr. More's scheme were carried into effect, would be "that at the end of 12,856.
the ebb the 50 million gallons would be tidal water previously stored, as against clean water coming over Teddington Weir"; but he adhered to his opinion that this
would cause an appreciable injury to the river, and he carried his objection so far as 12,957.

12,859. to say:—"It is so important a factor, that every drop of water that you reduce, I do not care whether it is a gallon, in those critical states of the river in the summer time is of value in purifying it." We are of opinion that this is much too strongly put, and that Mr. Binnie is greatly overstating his case.

78. After carefully considering the evidence of Mr. Hawksley, Mr. Marten, Mr. Baldwin Latham, and Mr. Birch, we are of opinion that Mr. More's suggestion is a practicable one, and that no good reason, from an engineering point of view, has been adduced why it should not be carried into effect, but strong local objections would probably be raised against such a scheme, and we do not intend to recommend it, as the sequel of our report will show.

(2.)

Thames Valley.

79. The Thames companies' officers, in stating their respective cases, have assumed that no more water is to be taken direct from the river than the 130 millions of gallons authorised by arrangement with the Thames Conservators, and that the balance for future wants up to 1931 shall be obtained either from the valley gravels or from wells in the chalk; but schemes were formulated by other engineers for more fully utilising the Thames by the construction of impounding reservoirs, and we will now proceed to deal first with the suggestions made by Mr. Henry Robinson, M. Inst. C.E., Professor of Engineering at King's College.

Mr. Robinson's Scheme.

App. C. 33. **80.** Mr. Robinson recommends the construction of three reservoirs in the Kennet Valley, to contain between 46,000 and 47,000 million gallons, by means of which the minimum flow at Teddington Weir would be increased to 300 million gallons per day, leaving a further 300 million gallons per day for purposes of water supply. The drainage area to the reservoirs would be 350 square miles, five-sixths of which consists of chalk and other pervious material. An examination of the plans and sections which have been submitted leads us to believe that the possibilities of constructing watertight reservoirs on the sites suggested is not proved, and, in fact, we believe that the probabilities are
7772. the other way. The possibility depends entirely upon the existence of a continuous sheet of the mottled clay over the entire floor of the valley, and we do not consider that the sections furnished prove this to be the case. Further, it is not certain that the bed known as the mottled clay is of uniform character wherever it occurs, and it seems highly probable that it may include beds of sand, which would, in certain circumstances, make the construction of the reservoirs extremely difficult and expensive.
7759. Another objection to this scheme, equally serious, is, that five-sixths of the drainage area is pervious. No doubt much of the rain which falls on and sinks into the higher portions of the area is returned into the river lower down. But we have absolutely no knowledge which would entitle us to say that a considerable quantity of the rainfall may not be entirely lost by flowing through underground channels into the drainage areas below that under consideration. It is to be regretted that
7763. during the time occupied in the preparation of this project the opportunity was not
7768. taken of gauging the flow of the Kennet at the site of the proposed reservoirs. Even a series of measurements extending over only six months would have been very useful, as some approximate deductions might have been drawn by comparing them with the continuous gaugings at Teddington on the Thames.

The scheme as put before us is a very bold and ambitious one, the main reservoir suggested having a capacity three times that of the largest ever made in this country viz., the Vyrnwy Reservoir of the Liverpool Corporation. Its estimated cost is three millions sterling, and manifestly, therefore, its construction ought not to be attempted unless it can be incontestably proved beyond a shadow of doubt that it would be in every respect successful. After giving the scheme our most careful consideration, we are of opinion that the data upon which it is founded are unreliable, both in respect of the volume of water that can be collected from the watershed, of the water-tightness of the reservoir sites, and of the methods of construction which are indicated, and we cannot therefore advise its adoption as a satisfactory mode of providing storage.

Messrs. Marten and Rofe's Scheme.

App. C. 36. **81.** The second scheme of storage submitted to us was prepared by Messrs. Marten and Rofe on behalf of the Thames Conservators, and consisted of nine reservoirs, to

be constructed upon various tributaries of the upper Thames. Both these gentlemen have had considerable experience in hydraulic works, and Mr. Rofe has been engaged upon the construction of difficult and important impounding reservoirs. After selecting the various sites upon topographical and geological grounds, the advice of Messrs. Henry Woodward, Horace Woodward, Topley, and Boyd Dawkins was sought as to their suitability from a geological point of view. On the other hand, we have been assisted by the evidence of Mr. Binnie and Mr. Deacon, as engineers, and Professor Green, as geologist, in criticism of Messrs. Marten and Rofe's proposals, and as these two groups of witnesses have not been quite in accord we have had to judge between them.

The precise function of these reservoirs was to provide from store 130 million gallons a day for supply, and at the same time to compensate the river to the extent of nearly 30 millions. As the quantity now authorised to be taken direct from the Thames is 130 million gallons a day, this really means the doubling of the supply from that source. It was assumed as the basis of calculation that droughts of 120 days should be provided for, and that therefore $130 + 30 \times 120$, or 19,200 million gallons of storage would be required. The nine reservoirs laid out would contain something more than this quantity.

82. We may say at once that the whole of these reservoirs did not receive the unqualified approval even of the witnesses called for their promotion. Thus Mr. Marten himself casts 8115,
a doubt upon the suitability of Nos. 7 and 8, which are on the Rivers Glyme and 8140-1.
Dorne respectively. Mr. Topley declines to speak with equal approval of all the sites. 8617-9.
He says "I think there is considerable doubt as to two or three of them. * * * 8667.
In my statement to-day I have said that there is a possibility of that reservoir 8670.
(No. 2.) not holding the water perfectly."

Dr. Henry Woodward said, "I may say that we should not have thought of looking 8731.
at these sites because of their being on the great oolite but for the fact of the existence of the Blenheim Lake. That led us to go up this valley and examine the sites there, and seeing the water holding capacity of that lake we were led to believe that these other valleys would prove equally suitable." Now this Blenheim 8115.
Lake is, according to Mr. Marten, only 22 feet deep at the bank or outlet end, and by Professor Green's evidence, only 20 feet. It had to be repaired some 20 years 8293.
ago, and there are leaks about the bank site at the present time. Its existence is hardly a sufficient guarantee that reservoirs with twice the depth of water would be watertight.

Mr. Horace Woodward in speaking of No. 1 says that although there is a slight 8798.
defect in the site "when you come to consider the dam and the wing trenches that would be made it would be a perfectly sound site." Of No. 2 he says, "I think a 8804.
certain amount of water would be likely to escape through the inferior oolite. It is one of those reservoirs which would not be perfectly watertight, I think." In later 8807.
answers he further depreciates this site. Of No. 3 he says, "I think it would be all 8824.
right, because of the fact that the marlstone (in the floor) would be waterlogged, and I do not think water would get away very far to the south-east." As to 8834.
No. 4 Mr. Woodward's evidence is somewhat more emphatic. (*Q.*) "You think that this particular reservoir, then, having a floor of lias clay and with sides of middle lias would give a perfectly satisfactory reservoir? (*A.*) I think so, quite satisfactory. (*Q.*) As much as the first we have considered? (*A.*) Well almost so; of course we 8835.
have got more of the loamy beds of the middle lias, that is the only difference, but I do not think they can be very leaky." No. 5: "Would be practically water- 8841.
tight." As to No. 6, Mr. Woodward said the site "was very favourable." 8848.

Speaking of Nos. 7 and 8, Mr. Woodward said that the upper parts (about 30 feet) 8855
would be mainly very porous limestone, and he accepted the suggestion that it would be capable of intercepting runnels of water, but completely inadequate to check 8857.
anything more. Mr. Woodward was of opinion that if these two reservoirs were not otherwise quite watertight, a natural deposit of blue mud brought down by the 8865.
stream "would be very useful in stopping up any little leakages that might happen." No. 9, he said, was on the Kimmeridge clay, and would, he believed, be an absolutely 8875.
watertight site.

With regard to these reservoirs generally, Mr. Rofe expressed the opinion that by providing wing trenches they could be made to hold water. He admitted that they were not ideal sites, but said that he was sure better could be found in the tributary 8296.
valleys of the upper Thames.

83. The impression conveyed to our minds by the evidence as a whole, given by the projectors and supporters of these reservoirs was that they were not entirely satisfactory. None of the witnesses spoke with any enthusiasm in their favour; on the contrary, a somewhat apologetic tone was adopted throughout. From the opponents, on the other hand, came very emphatic condemnation of most of the sites.

To begin with Mr. A. H. Green, Professor of Geology in the University of Oxford:

To No. 1 Reservoir he gave only a qualified geological approval, even if wing trenches were made for three-quarters of a mile on each side up from the main dam
9349. out of a total length of two and three-quarter miles. He condemned this reservoir, however, as being too shallow, stating that at the upper end, "You would have three-quarters of a mile of noisome swamp, full of all sorts of pestilential growths that would render a very large portion of its contents not only useless but absolutely
9352. pernicious." With regard to No. 2, Mr. Green said, "I should be sorry to speak quite positively on the point, but my impression is, that the only way to make this reservoir hold water is to carry a wing trench all round it; to surround it with
9353. a puddle trench that will be possibly 100 feet deep all the way round." (*Q.*) "In other words you think it practically impossible?"—(*A.*) "I should think it practically impossible so far as I can judge."

9358–74. As to No. 3, in the course of a long examination upon this site, Mr. Green said, "I do
9360. not know what length of wing trenches might be required to prevent the water getting round the ends of the puddle wall. I think it is possible they might have to go all round the reservoir, and one arm of it is four miles long, and the other
9373. arm is two miles long." At the close he was asked as follows: (*Q.*) "Then your opinion is that the sides as well as the bottom of that site would not be sufficiently impervious for the construction of a reservoir?"—(*A.*) "It can only be constructed
9374. by works of such a character as I have indicated." (*Q.*) "You mean that the rocks themselves are not suitable for a reservoir?"—(*A.*) "No, I think not."

9376. As to No. 4, Mr. Green said, "The bottom is very largely on pervious marlstones."
9377. The sides also towards the lower end are almost entirely on marlstone, and for a long way up the south side of the reservoir the upper part of the water would also rest
9386. on porous marlstone." About No.5 he wound up his criticisms by saying, "It would
9388. be very difficult indeed to make No. 5 watertight, I think." As to No. 6, he admitted there would be no difficulty in making it watertight, but described it as a shallow pan, the upper end of which would be a mere swamp.

9389. With regard to Nos. 7 and 8, Mr. Green contended that it was quite misleading to calculate upon making them watertight, because of the existence of the Blenheim
9396. Park Lake. He said that, from information supplied to him, the depth of this had been overstated and was nowhere more than 20 feet, and that the water did to some extent
9399. percolate through the bed of the lake underneath the dam. He dissented from Mr. Horace Woodward's view that the natural puddle could rest on the sloping sides.
9400. He said, "I paid very great attention to it and I quite convinced myself that no amount of natural puddle sufficient to make the slopes watertight existed." As to
9403. No. 9, Mr. Green agreed that it could be made watertight with ease.

8015. **84.** Mr. Binnie said, "Out of the nine reservoirs (proposed by the conservators), seven I say at once could not be constructed at all, at least they might be constructed but they would not hold water. The remaining two could be constructed, one at great risk and great expense, and possibly when finished would not be watertight. The other could be constructed and filled with water, but it would be a swamp receiving the drainage of surrounding places and totally unfit for use." At a later stage
11,441,*et seq.* Mr. Binnie criticised these reservoirs adversely as Mr. Green had done on account of their shallowness.

11,362–83. Mr. Deacon in his evidence given on the 25th day, practically endorsed Mr. Green's condemnation of the sites; he also said that he believed the collectable water had been
11,360. considerably over-estimated by Messrs. Marten and Rofe.

85. It is not necessary to quote further evidence respecting these sites. Sufficient has been said to show that we are justified in not looking upon them with much confidence. Independently of their individual demerits, their position high up the watershed of the Thames is objectionable, inasmuch as if they were recommended we should have to consider carefully how their construction and use would affect the interests of riparian proprietors and others upon the main river, and the tributaries specially disturbed. If it turns out that storage on a large scale must be provided somewhere, it is manifest that the nearer it is located to the present intakes the better,

because the whole watershed area above the point of abstraction would be absolutely unaffected.

Messrs. Hunter and Fraser's Scheme.

86. The third proposal as to storage has advantages over any other in this respect. It was laid before us by Mr. Walter Hunter, M.I.C.E., a director, and Mr. Alexander Fraser, M.I.C.E., the engineer, of the Grand Junction Company, and consists in the construction of nine reservoirs upon land in the neighbourhood of Staines at only a few miles distance above the existing works of the companies. These would be essentially different in character from those proposed by Messrs. Marten and Rofe, which were to be formed by damming up natural valleys, as the storage capacity would be obtained by excavating below the surface in almost flat ground and forming the material removed into banks so as to increase the depth. By this combined process of sinking and raising, a depth of 40 feet would be obtained, the digging being entirely in gravel which overlies the clay to a depth of from 20 to 30 feet. Apps. C. 66–7. 11,247–338.

Water-tightness is to be secured by forming vertical puddle-walls in the hearts of the banks, carried down by trenches into the clay below, the internal slopes being protected from wash by a concrete lining. This is a common and effective method of construction in such situations, and there can be no doubt that perfectly safe, sound, and satisfactory reservoirs can in this way be ensured.

An advantage rightfully claimed for this scheme is, that it can be carried out by instalments as may be required by the increase of population. The complete scheme is intended to provide for the taking of 300 million gallons a day for supply, and still to leave 200 million to flow over Teddington Weir. The promoters have assumed that this quantity will not be needed until 1941, and that to secure it 17,526 million gallons of storage will then be required, this having been gradually built up by instalments as follows, viz. :—

By 1901 - - -	1,896 millions.
„ 1911 - - - -	3,322 „
„ 1921 - - -	5,116 „
„ 1931 - - - -	8,609 „
„ 1941 - - -	17,526 „

The water to be stored is to be taken from the Thames at a point above Staines. The levels would admit of its flowing in partly by gravitation, but mainly it will have to be pumped, as the top water level is to be 80 feet above O.D., the ordinary water level of the river at the point of abstraction being 50 feet above O.D. From these reservoirs the water would gravitate through cast-iron conduits constructed in the clay to filter-beds at Hampton and Molesey, but when occasion arises in the future the filtering can be done at Staines either through the natural gravel or artificial beds as may then be deemed best.

It is proposed that no water shall be taken from the river during the first 15 days of any flood, and the pumping charges have been made out on the assumption that four of such floods may occur in a year, and that the water drawn from store during the 15 days shall be replaced again by pumping in 20 days. At all times it will be possible to exercise a selective judgment as to the taking of water, and in these respects the scheme excels the upper Thames proposals, for there the water would pass into the reservoirs at all times and in all conditions, no bye-flood channels being intended. The reservoirs would, in fact, depend for their supply upon the flood waters, which would at times be very objectionable.

On this question of storage Mr. Hawksley stated that the quantity suggested as 7158.
likely to be required in the future by Mr. Binnie could be obtained by means either of the storage reservoirs proposed by Messrs. Marten and Rofe in the upper Thames or by Messrs. Hunter and Fraser near Staines. About some of the former he spoke 7159.
in terms of only qualified approval, but stated that there were other sites in the adjoining districts, notably one on the main river above Oxford, where ample storage 7309–12.
capacity could be provided.

With regard to Messrs. Hunter and Fraser's scheme for the Staines Reservoirs, Mr. Hawksley and Sir Frederick Bramwell reported jointly to those gentlemen as follows :—

"We have carefully considered your proposal for increasing and otherwise improving App. C. 66.
the capabilities of the River Thames for the supply of the metropolis and its vicinity when and as may be wanted at any time or times during the ensuing 50 years, and

we are pleased to have the opportunity of stating that we approve in general terms of that proposal.

"We beg leave to express our opinion that the sites proposed for the reservoirs are suitable for their intended purpose, and that the reservoirs are capable of being constructed at a moderate expense, and we think that this project may very properly be placed before the Commission as one amongst others to show that the watershed of the Thames affords ample facilities for increasing the supplies of water to the metropolis when and as they may be required."

87. Broadly speaking and without committing ourselves to details, we may say that the conception of this Staines scheme of storage commends itself to us as the best which has been suggested. It affects but a short run of the main river and none of the tributaries. It can be carried out by stages, as the demand for water grows, and can be delayed or stopped entirely, as circumstances may dictate in the future. On economical grounds it thus has a marked advantage over the Kennet scheme.

The proposed sites for storing the water of the Thames at Staines are from a geological point of view quite unobjectionable. They lie upon the alluvial plain of the river, and will require to be excavated in the sheet of gravel which forms that plain. No borings have been submitted to us showing the depth of gravel at the locality, but it is probably about 20 or 25 feet. Underneath it lies the thoroughly impermeable London clay which would form an entirely satisfactory bottom for the reservoirs.

Lea Valley.

Mr. Bryan's Scheme.

App. A. 11. **88.** In addition to the storage reservoirs suggested to be made in the Thames valley, Mr. Bryan has laid before us a project for others in the Lea. These are to be located just above the existing reservoirs of the East London Company at Walthamstow, and to extend up the valley for a distance of $4\frac{1}{2}$ miles. The Company has at present storage for 740 million gallons, and proposes immediately to increase it to 1,200 million by raising the banks of the Race Course Reservoir, and constructing two new reservoirs on land in its possession. In addition to these projected extensions Mr. Bryan stated that four reservoirs might be made containing together 7,130 million gallons. These reservoirs would be constructed in the same manner as those of the Staines scheme already described, viz., partly by excavating and partly by embanking, watertightness being ensured by puddle walls in the banks tied into the clay underlying the superficial gravels.

By means of this combined capacity, Mr. Bryan estimates that 60 million gallons a day may be obtained from the river by his Company without prejudicially affecting its condition or interfering with navigation, the maximum take having hitherto been about 37 millions. With the $22\frac{1}{2}$ millions constantly abstracted by the New River Company at Hertford, this would bring up the quantity taken from the Lea to $82\frac{1}{2}$
12,196. million gallons, or 4·483 inches of rainfall on the 460 square miles which Mr. Bryan stated as the watershed area above the lower intake of the Company. If the Thames area of 3,548 square miles above the present intakes were utilised to the same extent, 636 million gallons a day might be obtained from it.

App. A. 7. The following note was appended to the estimate of capabilities in the original statement of the Company:—"The above quantities may be largely increased by the storage of river water that now runs to waste, as there are many sites in the Lea valley well adapted for the construction of large storage reservoirs." We take it that these reservoirs of Mr. Bryan's were designed merely to show (in confirmation of such note) the feasibility of providing in the Lea valley sufficient storage to admit of a great increase in the obtainable supply, up, in fact, to 60 millions a day, and not as intimating that the East London Company were seriously contemplating their construction. Mr. Bryan did not withdraw that original estimate which set out the company's views on this point as follows:—

	Gallons.
To be taken from the Lea and storage reservoirs, per day - -	30,000,000
From the Thames - - - - - - -	10,000,000
From the existing gravel springs at Hanworth - - -	2,000,000
From the company's existing wells in the Lea valley - -	11,000,000
From further wells, some of which are now being sunk - -	13,000,000
	66,000,000

(3.)

Gravel Beds.

89. With regard to the water obtained from gravel beds, we have referred at length to the evidence given by the representatives of the several companies, and we will now state our own views about these supplies, dealing first with the Lambeth works at Molesey. Paras. 51 to 56.

We have ascertained that in the reach of the river extending in front of these works, and, in fact, lower down opposite those of the Grand Junction and Southwark Companies, the dredging of gravel is almost continuously going on. Under normal conditions the gravel is coated with a few inches of fine argillaceous silt, which is not freely pervious; but where the dredging operations remove this, there is, of course, a free passage for water either from the land to the river, or from the river to the land, in whichever for the time being the water has a dominant head.

If the water in the gravel beds were left entirely uninterfered with, it would gravitate to the river as its natural outlet; the lower end of its gradient or slope being determined probably by the summer level of the river. In times of flood, when the water in the river may be raised several feet, the foot of this slope is first flattened and then reversed, so that the water flows copiously back into the ground.

90. The Lambeth Company has provided means for ensuring this reversal at any time by laying a line of perforated stoneware-pipes about 20 feet away from the river bank and parallel to it, and at a depth of 7 or 8 feet below summer level. These pipes communicate with a well from which the water is pumped, and its level is thus artificially depressed all along the line of the pipes, with the result on the one hand of steepening the slope of the land water and preventing it getting into the river, and on the other hand of creating a slope from the river landwards, and thus directly abstracting water from the river. Under these circumstances it appears to us clear that the Lambeth Company are not justified in claiming that the six million gallons a day they can obtain in this way should not be counted as part of their authorised 24½ millions. 2480–2.

91. On the north side of the river the natural conditions are practically similar to those on the south. To the north and west of the Grand Junction and Southwark and Vauxhall works there is an extensive tract of pervious sand and gravel beds into which the rainfall percolates, and flows underground, broadly speaking, in a south-easterly direction towards the river. From this bed both the companies did in former years pump a considerable quantity of water, and the Southwark and Vauxhall claim now to be able to procure three million gallons a day. The quantity has, however, been most materially diminished by the construction of the puddle wall previously referred to, as this obstructs the passage of all water coming from the west, and diverts it southwards into the river. There is, however, still the opportunity for some water to get into the gravel under the Southwark and Vauxhall Company's property from the north, but we doubt very much if anything like the three million gallons a day claimed as obtainable by their engineer, Mr. Restler, can be relied on. Para. 55.

It is, we think, quite clear that if an artificial depression is produced in the level of the water in the ground by pumping anywhere in close proximity to the river, water must inevitably be drawn out of the river, and it would be quite impossible to differentiate between that and the water flowing from inland which had never got into the river.

Mr. Restler based his opinion that the quantity pumped from the gravel beds (when none was being let in from the Thames artificially) was entirely land water upon the fact that it stood in trial holes, only a stone's throw from the bank, 2 or 3 feet higher than the water in the river, showing apparently no direct connexion. It cannot be questioned that this shows that there is an abnormally steep gradient, but our view is that this is to be accounted for by the existence of the coating of silt overlying the gravel which, though not impervious, requires a certain head to pass the water through it. Whether three millions can be obtained or not is of slight importance, for, whatever the quantity may be, we regard it either as water prevented from reaching the river, or abstracted from it. 2347–53.

Both these north side companies (as already mentioned) utilise the gravel "in situ" as a filter, for water drawn directly from the Thames through pipes laid in parallel lines a few feet below the surface, having open joints through which the water passes down into the gravel and is re-collected by similar pipes placed Paras. 52 and 53.

upon the top of the impervious clay, intermediately between those above and several feet below them. The water thus treated and collected is then conveyed to the pump wells.

The original intention of the engineers in devising this system was that it should take the place and answer the combined purpose of subsidence reservoirs and filter beds at considerably less cost, but the water examiner has not of late years permitted this water to pass into supply without going through the usual process of artificial filtration. The economical aspirations of the engineers have thus been only partially realised,
13,046. especially as it is found (as might have been expected) that the continuing delivery of turbid water into the gravel tends to foul and choke it, producing constantly diminishing efficiency, and, in course of time, resulting in absolute uselessness. So long as it remains available, this process can be regarded only as an adjunct to the filter beds and as a means by which the length of time they will work without surface skimming can be increased.

It has never been suggested that the water thus dealt with is anything more than a part of the quantity authorised to be abstracted from the river, and it must not therefore be confounded with the six million and three million gallons claimed, unjustifiably as we think, as being in excess of that quantity, by the Lambeth and Southwark and Vauxhall Companies respectively.

(4.)

Deep Wells.

92. In addition to this surface water, let us now see what are the estimates of the capabilities of the underground sources, meaning by this term the chalk only, and leaving out of account the gravel beds alongside the Thames, which, in our opinion, only yield water which would otherwise go to feed the river mainly above the tidal section.

66–7. *New River.*—Mr. Francis, the engineer of the company, stated that of the present average daily supply 2 millions of gallons were taken from the Chadwell spring, and $8\frac{1}{2}$ from the several wells sunk into the chalk. He estimated that from the wells $23\frac{1}{2}$ million gallons more could be obtained, bringing the daily yield from the chalk up to 34 millions.

East London.—The quantity now pumped from the chalk by the East London Company is irregular and uncertain, because the driving of headings leading to the wells is
648. going on, but Mr. Bryan estimates that six million gallons a day could now be obtained. There seems to have been a little confusion about the figures relating to this matter,
App. A. 7. but the formal statement shows that from existing wells, others in course of construction, and still others contemplated, 24 million gallons are expected to be obtained.

The two companies together assume therefore that they can ultimately procure from the chalk 58 million gallons a day. As compared with this figure, they were actually
58, 781–3. getting in 1891, New River $10\frac{1}{2}$ and East London about $1\frac{3}{4}$, making together $12\frac{1}{4}$ millions, or about $21\frac{1}{2}$ per cent. of the ultimate quantity assumed.

App. A. 22. *Kent.*—The Kent Company obtain the whole of the water they supply from chalk wells, the average quantity pumped per day in 1891 being 13,534,000, and the maximum 17,000,000. The estimated yield of the existing wells is 21,000,000, and it is believed that, by additional works on sites at present utilised, seven millions more may be obtained, and that from a new well at Kent Gate, West Wickham, another million, bringing the total up to 29 millions. In the opinion of the company's advisers a still further quantity might be obtained within their Parliamentary district.

93. In support of the evidence given by the New River and East London Companies' engineers, Mr. Hawksley, Sir Frederick Bramwell, Mr. Baldwin Latham, Mr. Topley, and Mr. Boyd Dawkins were called.

7173. Mr. Hawksley stated that the New River Company were pumping 13,200,000 gallons a day, that Mr. Francis (their engineer) believed they might pump 21 millions more, but that he was inclined to think this was an over-estimate of 10 millions. In his view, therefore, the New River Company can only obtain from the chalk (including, no doubt, the Chadwell spring) 24,200,000 gallons. The East London Company, Mr. Hawksley said, were pumping 2,800,000 gallons daily, and might, as Mr. Bryan assumed, obtain 20 millions more, making 22,800,000. His estimate,

therefore, of the total quantity of underground water procurable in the Lea valley was 47 million gallons a day.

Mr. Topley spoke only of the East London Company's proposals for the future, and he practically supported Mr. Bryan's estimates. He expressed the opinion that there was something peculiar in the geological structure of the lower part of the Lea valley 1089.
which enabled it to yield an unusually large quantity of water.

Mr. Boyd Dawkins, in Part III. of his original statement, gave it as his opinion App. C. 44.
that "by sinking new wells into the chalk through the London clay, and in the bare chalk area to the north of the tertiaries, at least 30 million gallons a day can be obtained from the area of the Lea by the two companies in addition to their present supply. This is 16 million gallons a day less than the companies' engineers reckon upon.

The view expressed in broad terms by the companies' witnesses was that a great 1039, 8707,
volume of water was constantly travelling slowly underground from the Colne and Lea 9012–4.
watersheds on the north and north-west of their wells in a south-easterly direction to its natural outlet in the Thames, and that from this stream they were now drawing a mere fractional quantity, which had no effect whatever upon the surface streams.

Mr. Baldwin Latham said "the effect of pumping is to influence only points below 7621.
the points of pumping. All (underground) water is moving in particular directions, and if I put a pump at a particular point I affect nothing above me. I may cause the water to fall a little, but I do not abstract any water, as all the water has to come through those particular districts to the lower point at which I abstract it. The only places I affect are those at lower points. Now there is nothing in the Lea valley below these points of pumping to be materially affected." (*Q.*) "Of course, if you 7622.
pump faster than the rate of issue of the springs above, you would affect it?"—(*A.*) "If you pump more than the actual area will yield, you lower the reservoir." (*Q.*) "You lower the chalk reservoir?"—(*A.*) "You lower the chalk reservoir." Then 7623
Mr. Latham goes on to describe a case at Croydon, where more water has actually been pumped than the area will yield, and where, in consequence, not only have wells been dried below the point of pumping, but where the water level has been so lowered above as to prevent a "bourne" flow which would otherwise have taken place.

It will be seen that the witnesses called to support the New River and East London Companies' engineers did not fully accept and endorse their views as to the quantities which might be pumped without prejudicially affecting other interests.

Summary of the Companies' Suggestions.

94. We are now in a position to summarise the total capability of supply laid before us by representatives of the companies, importing into it figures given in evidence subsequently to the delivery of the original formal statements.

	Gallons per day.
From the Thames with additional storage - - - -	300 millions.
From the Lea with East London Company's "*projected*" storage -	52½ ,,
From chalk springs and wells - - - - -	87 ,,
	439½ ,,
	say 440 ,,

THE CHALK AS A WATER-BEARING FORMATION.

95. There can be no doubt that for the water-supply of London the Chalk is by far the most important geological formation within the Thames basin. It is a porous substance into which rain readily sinks, and in which vast quantities of water are stored. Such portions of this underground water as rise to the surface flow out there in copious springs. But as the London Clay which overspreads most of the lower part of the basin, is a thick impervious covering, it prevents the water imprisoned within the Chalk from finding its way upward directly to the surface. In and around London this underground reservoir in the Chalk has been tapped by deep wells, which, piercing the stiff clay several hundred feet in thickness, allow the water to rise to the surface or to a variable distance from it.

No exact information is at present available as to the quantity of water stored in the Chalk or capable of being pumped from it. But some approximation to the truth

on this subject may be obtained by careful measurements of the rainfall over the chalk areas, and of the amount of percolation. The rainfall has now been ascertained with tolerable accuracy by the long-continued observation of rain-gauges distributed at numerous stations over the whole district. Valuable evidence on this subject has been laid before us, especially by Mr. Symons, who is the highest authority in this
3780–3839. country in regard to rainfall, and the average annual precipitation over each special district may now be regarded as known.

96. The question of percolation is much less easily dealt with. It demands not only a knowledge of the rainfall in regard to its total annual quantity, but an observation of the circumstances in which the rain reaches the ground whether in numerous slight showers or in less frequent but heavy falls. It requires also careful study of the varying nature of soils and sub-soils, of the declivities of the surface, the influence of vegetation, and other causes which affect the rate at which moisture descends into the ground. Much information has been obtained on this subject by artificial percolation-
9824–53. gauges, imitating as nearly as possible the conditions of nature. Valuable evidence on
8570–8704. the subject has been laid before us by Sir John Evans, Mr. Topley, Mr. Easton, and
11,952–12,088. other witnesses.

In considering the percolation over the Chalk area of the Thames basin we must bear in mind that the chalk does not everywhere form the surface rock; over much of its extent it is covered by outliers of Tertiary strata, by "clay with flints" or by various kinds of superficial "drifts." Some of these surface deposits are so pervious that their presence does not sensibly affect the descent of rain-water into the chalk. But others are only partially pervious, their sandy portions allowing the water to descend freely, while their mixtures of sand and clay retard its descent, their more thoroughly clayey parts being practically impermeable.

97. While all bare chalk is singularly pervious to rain, local differences are observable in the rapidity with which water disappears from its surface. The surface of the chalk
App. C. 49. is frequently perforated by "pipes," "sinks," or "swallow-holes" formed by the solution and removal of the chalk by descending water. These cavities, though generally filled with gravel or soil, must often communicate downward with open passages and fissures, so that the rain which flows into them speedily finds its way by such channels into the body of the chalk.

The formation of communications of this nature with the surface of the ground serves a double purpose in the hydrological economy of the chalk. Not only are conduits thus formed for the admission of surface-water, and its access into the general body of the underground chalk, but channels are also provided whereby in exceptionally rainy seasons or at certain localities, even in ordinary times, the subterranean water may find its way upward and issue in springs or join the water flowing in the beds of streams. As an illustration of this we have had cited to us the case of the Thames
10,039–41. which is believed to receive considerable additions from water issuing from the chalk in its bed. The volume of the river is greater than, from the gaugings taken immediately above, it should be. As there is no visible source from which the addition can come, it is regarded as rising immediately out of the chalk. At Erith large bodies of water
9694. are actually seen issuing from the bed of the river. In like manner the Lea below Hertford increases as it flows along by additions poured into it from the chalk over which it passes.

1021, 8557, 9023, 9143, 9672. The most striking example of the abstraction of water from a running stream into the cavities in the chalk is that of the Mimms Brook. In the district traversed by this stream the chalk is perforated by numerous irregularly cylindrical cavities and open fissures. Some of these may be traced on the sloping ground above the level of the brook, while others may be observed in the channel of the brook itself, or within the limits which the water overflows in floods. In seasons of drought the water entirely or almost entirely disappears from the surface. After the long period of dry weather during the spring and summer of 1893, the locality was visited by two of our number, who found the channel of the main stream quite dry, and showing here and there the "sinks" or hollows that mark the positions of the swallow-holes, and in some cases the actual cavities descending into the bare chalk. When rain falls heavily the collected drainage fills the channel in the upper part of the brook, and flows onward until lost in the swallow-holes. As the wet weather continues, the stream is enabled to advance further and further as each successive cavity below is filled up. So capacious are some of these subterranean conduits, that the full stream may be seen descending bodily into one of them, while not a drop of water passes down the channel beyond.

It is conjectured that the water which thus disappears from the surface finds its way into the basin of the Lea and helps to feed the springs there. But when all the swallow-holes are filled up and a continuous stream of water passes over the surface it falls into the basin of the Colne. App. H. 1.

Reference may also be made here to the intermittent streams or "nailbournes" so well exhibited in Kent, the appearance and disappearance of which are directly connected with cavities and underground channels, into which the water sinks and from which it issues again at some lower part of the valley. 11,553–64. 11,663–6. 11,850–5.

Though the chalk is generally fissured and traversed by swallow-holes this structure is nowhere, perhaps, so marked as in the Mimms district. It is evident that throughout a considerable part of the year, the whole of the rain which falls on the 20 square miles drained by the Mimms Brook passes underground, and goes to supply springs and artificial wells in some other drainage area.

98. In order to form a satisfactory judgment on the probable amount of rain that is absorbed over the various chalk areas in the basins of the Thames and Lea, it is obviously necessary not merely to know the extent of these areas in square miles, but also the relative proportions of surface where the chalk is quite bare, where it is covered with pervious materials, and where it is more or less protected by mixed or practically impermeable deposits. We have been much aided in this inquiry by the statistics carefully compiled by Mr. Topley. App. C. 41.

Chalk areas in Thames Basin above Intakes of Companies.

99. Taking that portion of the Thames basin which lies above the intakes of the companies, we find that the total area of Chalk in it is 1,005 square miles. Of this area there are 292 square miles covered with superficial drifts of a mixed or partly permeable, partly rather impermeable, character; 135 square miles are covered with pervious deposits, leaving 578 square miles, or rather more than half of the whole area, where bare chalk comes to the surface. If, however, we take the bare chalk, and the chalk concealed by a permeable cover to be for our present purpose the same, the whole area of readily permeable material forming the surface in this portion of the Thames basin above the companies' intakes is 713 miles.

Along the outside of the Chalk area, where the chalk forms an escarpment, a narrow strip of ground slopes steeply away from the Thames, and the streams which issue from this escarpment seem to flow out of the river basin, for some of them enter the area of the Jurassic rocks. But this loss is only apparent, for they join streams which descend from the Jurassic hills, and eventually return into the Thames

By far the largest part of the drainage of the Chalk area is carried into the Thames either directly from the chalk itself or across the great plains of Tertiary sands and clays.

100. Among those who have studied the question of percolation into soils, sub-soils, and rocks, considerable difference of opinion exists as to the average rate of percolation in certain materials, and as to the ratio between the percolation and rainfall. For purposes of water-supply it is not safe to take an average of years. Provision should be made for an adequate water-supply even in the driest years, and it is probably the wisest course to estimate what the minimum yield of water from the Chalk should be in years of drought. Two observers, Sir John Evans and Mr. Hopkinson, have 9835, 8353. given their opinion that while the average percolation for a number of years may amount to from 7 to 10 inches annually, the amount in a succession of dry years may be not more than 4 inches. If then not more than 4 inches of the total rainfall could be relied upon as available in outflow from the 1,005 square miles of chalk area in the Thames basin above the companies' intakes, the total daily yield, reckoning as usual that 1 inch of annual percolation is equal to a discharge of 40,000 gallons a day per square mile, would amount to 160,000,000 gallons.

Certain deductions must be made from this amount. The wells sunk into the Chalk above London abstract a portion of the water. How much is thus abstracted is not known, but it must obviously be but a small fraction of the total quantity. Besides, after being used it is returned to the streams or to the land, and thus reaches the Thames again above the intakes.

No doubt a large quantity of water could be collected by sinking wells and driving galleries in the Chalk above the intakes. But any such abstraction would probably be at the expense of the springs and streams feeding the Thames, and would proportionately diminish the flow of the main stream in dry weather.

Chalk under London.

101. In the area under London, deep wells drawing water from the Chalk have been in operation for many years, and the number of such wells has greatly increased. Mr. Binnie has made inquiry into the past history and present condition of no fewer

App. C. 4. than 172 chalk wells within and outside the county of London. It is difficult to obtain accurate statistics as to the quantity of water daily abstracted by these wells, many of the owners refusing to give information regarding them. But the amount so obtained

8720, 9480. has been estimated at about 10,000,000 gallons per day. Some of this water is derived from the outcrop of Chalk to the south of London (Mole, Wandle, Ravensbourne) which drains into the Thames below the intakes, the rest comes from the Chalk above the intakes.

It is evident that even the comparatively large amount of water pumped from under London can make no appreciable diminution of the vast store collected by the Chalk above the intakes. This great subterranean reservoir discharges its overflow partly by springs and streams into the Thames, but probably also in part by flowing eastwards under the Tertiary covering into the lower part of the basin of the Thames.

On the question of the effect of pumping from deep wells on the water-level in the chalk much evidence has been brought before us, and various entirely contradictory opinions have been expressed regarding it. But there is one branch of it on which there seems to be a general agreement, viz., that under London the water-level has been materially lowered since deep wells have been sunk in many parts of the metropolis.

104, 7905, 7965. Mr. Francis estimates the fall at nearly 18 inches in the year; Mr. Binnie makes it 12 inches.

The mere number of wells actively pumping within a limited area might be held to account for the lowering of the water-level, but the rate of subsidence under London seems to be so much more rapid than in other districts that there may be some

9579, 11,497. special and local reason for it. Mr. Whitaker suggests that the Chalk lying under London is compressed by reason of the great overlying masses of Tertiary strata and also from its lying in the centre of a basin. Its pores and fissures are thus pressed together, and water does not find so easy and rapid a passage through it as through chalk which rises to the surface. According to this view the wells in London have been abstracting water from the chalk faster than it can flow in from the outcrop, so as to cause the water-level gradually to sink.

Chalk areas below companies' intakes, south side of Thames.

102. In dealing with the chalk areas in the basin of the Thames below the companies' intakes it is clear that any water taken from these areas cannot affect the Thames above the intakes.

On the north side of the Thames these Chalk areas lie properly within the basin of the Lea and will be separately noticed. On the south side of the river they lie partly within the districts of the Southwark and Vauxhall, Lambeth, and Kent Companies, and partly to the eastward of these in areas which are not included within the districts of any of the metropolitan waterworks.

The Chalk areas south of the Thames and below the intakes are already to some extent drawn upon for water-supply to London. The Kent Company now derive their whole supply from the Chalk, out of which they estimate that by means of wells upon their present stations and lands they could obtain a daily yield of 29,000,000 gallons. The Southwark and Vauxhall and the Lambeth Companies propose to increase their supplies by sinking wells in the Chalk within their respective areas. The Southwark and Vauxhall Company has made an experimental well at Streatham, from which nearly 2,000,000

2397. gallons a day were pumped and which it is believed will yield 3,000,000 gallons. No

2426–7. doubt some proportion of this water comes from the Thanet Sand which lies above the Chalk, and through which this well is sunk. But the outcrop of this sand is so narrow that it can hardly of itself supply the large quantity of water raised at the Streatham well, and from numerous others in the lower part of the Wandle basin. It has been

2696–2707, 2744–7, 2750–8, 7576. suggested that the water thus raised from the Thanet Sand is really chalk-water which finds its way into the sand from the Wandle where that stream runs across its outcrop. Whatever be its origin the quantity of water yielded by the Thanet sand in this district is considerable. A large number of wells in the lower part of the Wandle Valley still

2731. overflow.

How far extensive pumping would affect the water-level in this part of the basin has not yet been ascertained. It should be noted, however, that when the experimental well at Streatham was being actively pumped the water-level in surrounding wells sank. There seems good reason to conclude that pumping on a large scale in the lower part of the basin of the Mole and Wandle could hardly fail to affect seriously the local supplies.

The Southwark and Vauxhall Company proposes by means of seven wells yet to be sunk to raise $10\frac{1}{2}$ millions of gallons a day in addition to the amount drawn from the Streatham well. The Lambeth Company has also contemplated increasing its supplies by drawing upon the Chalk. It anticipates that from a single well at Selhurst, recently sunk, a supply of 3,000,000 gallons a day can be obtained.

649.

2594.

It will be seen that these estimates of the two companies refer to practically the same districts, and the proposed wells are not unlikely to interfere with each other.

103. Taking the whole Chalk areas traversed by the rivers Mole and Wandle we may conclude with some confidence that their subterranean water supply is not yet drawn upon to its full capacity. But there will no doubt be strong local opposition to any proposal to increase the London water-supply by sinking new wells in this area. Croydon, which lies within the district, is a rapidly increasing town which will certainly require large additions to the supplies which it draws from the Chalk. Any serious pumping here would no doubt diminish the flow of the Wandle, and as the mill rights 7601. and fishing rights on this stream are valuable strong opposition would probably be offered to the abstraction of large quantities of water. Another point requires to be kept in mind. If, as already remarked, the wells in the Thanet Sand derive a large proportion of their water from the Mole as it flows over the outcrop of that formation, any marked lowering of the stream might be expected to affect the supplies of these wells.

The circumstances of the upper part of the basin of the Mole are somewhat different from those of the Wandle. Probably a considerable quantity of water could be obtained from the Chalk in this area. But there would undoubtedly be a limit beyond which the flow of the stream would be injuriously affected. And there would also be the further objection that any operations which in the upper part of the Mole basin seriously diminished the volume of water flowing through the Chalk would reduce the available supplies underlying the Tertiary strata to the north in the very district from which the two companies just mentioned propose to obtain additional water.

104. The Kent Water Company affirms that, from its wells already in use, it can give a daily supply of 21,000,000 gallons. The area of Chalk within this company's district is stated to be 93 square miles, but it is said that other 17 square miles contribute to the supply, giving a total of 110 square miles as gathering ground of chalk within the limits of the Company's present powers. There seems no reason to doubt that 2923. a considerable addition to the amount of water that can now be raised by this Company could be obtained by sinking other wells.

Mr. Whitaker estimated that double or perhaps treble the amount now obtained 9483–4. could be raised. Mr. Latham also gave important evidence regarding the great 7583–4. additions that could be made to the present water-supply from the Chalk areas to the south of London.

Chalk wells in Essex.

105. East of the valley of the Lea the thick Tertiary covering spreads over the county of Essex, concealing the Chalk which lies several hundred feet below. If any large amount of water could be obtained by sinking wells into the Chalk in this district it would not affect any surface supplies. The district would in that respect be free from the objections raised elsewhere to extensive pumping. But, though water would almost certainly be found below the base of the Tertiary formations, there seems good reason to anticipate that it would be small in amount. The northern outcrop of the Chalk is many miles distant. And the same geological structure which has already been referred to as probably retarding the flow of water below London exists also in Essex. Mr. Whitaker stated in evidence that he could not anticipate that any considerable quantity of water could be obtained from that district. The ground 9503. east of the Lea basin and north of the Thames may be left out of account in any inquiry into the future water supply of London.

Chalk area of East Kent.

106. In the course of evidence given by Messrs. Whitaker, Topley, and De Rance, regarding supplies of water from the Chalk in the eastern part of the Thames valley, it became clear to us that further detailed information was desirable regarding the geology and water-yielding character of that district. There seemed a strong probability that a large amount of water might be obtained there with little disturbance of any surface rights, and it appeared to us necessary to institute a special inquiry on the subject. Accordingly we requested Messrs. Whitaker, Topley, and Easton to make a Apps. C. 42 careful examination of the ground and report to us. Mr. Whitaker and Mr. Topley, and 51. as officers of the Geological Survey, are intimately acquainted with the geology of the district, and Mr. Easton in his duties as an engineer has had occasion to pay close attention to the streams and springs.

The area, of which we shall now give a brief description, embraces the long strip of chalk country which rises along the south side of the Thames from the limits of the Kent Company's district, or, speaking generally, from the western limit of the watershed of the Medway to the Strait of Dover. We exclude from consideration north-east Thanet and the ground which drains towards Dover, as not being within the basin of the Thames, and, therefore, not properly coming within the terms of the reference of the Commission.

Throughout this district the Chalk forms a range of downs which descend in a steep slope towards the south, and fall more gently on the north side into the Thames. The chalk may be spoken of as a thick bed, inclined at a gentle angle towards the north-east and presenting its escarpment towards the south-west. While the base of the escarpment lies at sea-level at the coast, and at the Medway, it rises to 100 feet above that level at Stour, and to from 400 to 500 feet at the watersheds. The summit of the escarpment generally exceeds 500 feet and sometimes even 700 feet above the sea. From that elevation the ground gently slopes into the more level strip of Tertiary strata which skirts the southern margin of the estuary.

This sloping sheet of Chalk has been trenched by a number of valleys which run northward and carry the drainage of the country lying to the south of the escarpment into the Thames estuary. The bottoms of these valleys are coated with alluvial
11,553, gravel and silt. Some of the streams are "nail-bournes," that is, they are dry in
11,850. seasons of drought, and appear, sometimes from several places at the same time, as the water-level in the chalk rises after rain.

The surface of this sloping plateau does not lie everywhere on bare chalk. On the contrary an irregular and variable cover of "drifts" rests upon the chalk, being thickest towards the west and thinnest in the extreme east part of the district.

In order to compare the absorption-capacity of this Chalk area with others in the basins of the Thames and Lea, Mr. Topley has been good enough to compute the relative areas of bare and variously covered Chalk. Taking first the part of the district lying to the east of the Kent Company's ground but to the west of the Medway, the total Chalk area amounts to 78 square miles. Of these 47 are bare Chalk, 18 "mixed" drifts, and 13 chiefly permeable outliers and spurs of Lower Tertiary strata. The total extent of chalk east of the Medway amounts to 361 square miles, whereof 207 are bare chalk, 136 "mixed" drifts, and 18 chiefly permeable Tertiary materials.

Following again the same calculation as in the previous cases, we find that, assuming an average annual percolation of only four inches over the whole Chalk area, the 78 square miles west of the Medway should yield 12,480,000 gallons a day, while the 361 square miles east of that river should afford 57,760,000 gallons, or in round numbers a daily supply from the whole Chalk area of 70,000,000 gallons.

The assumption of only 4 inches of percolation over this chalk area may be objected to as too low, a much higher figure having been generally taken. If we take the amount to be as much as 7 inches, which will still be allowed to be a moderate computation for an average of ordinary years, then the area west of the Medway will yield 21,840,000 gallons a day, and the ground to the east 101,080,000 gallons, or say 123,000,000 for the whole district of Chalk.

The great proportion of the water thrown out from the Chalk in this part of Kent, is not utilised for waterworks, but runs out into the Thames. Perhaps about 10,000,000 gallons are pumped daily from wells in the Chalk within the district.

107. In order to test as far as possible by actual measurement the amount of water given off from the Chalk within a given drainage area, the gentlemen above named made observations in the small basin which drains into the sea between Dover and St. Margaret's. In geological structure and general physical features this limited tract so precisely resembles the whole chalk district that it may probably be safely taken as typical.

At the base of the chalk-cliffs between Dover and St. Margaret's, some strong springs issue on the beach and flow directly into the sea. The area from which the water in these springs is derived was estimated by Messrs. Whitaker, Topley, and Easton, at 11 square miles. There is necessarily much uncertainty in determining
11,737. the areas of underground drainage-basins in the chalk, and Mr. Easton confessed that in this case there were elements of doubt which made it difficult to arrive at reliable figures. He thought that the area taken as 11 square miles might not have been more
12,024. than $9\frac{1}{2}$, but he was disposed to include an area of 15 square miles as possibly contributing to the springs on the beach. We inquired particularly into the grounds

on which these estimates were based, and though there was undoubtedly room for difference of opinion as to the precise limits of the subterranean drainage basin, its total area for purposes of comparison might perhaps be assumed to be somewhere about 12 square miles.

Three sets of springs at the locality referred to were gauged in December 1892, 11,977.
and again in January 1893. On the first occasion they were found to yield 5,500,000 gallons a day, and on the second occasion 6,000,000. It is important to ascertain whether these figures exceed or fall below the average winter-yield. In the middle of the winter the flow of springs is usually about its lowest. Mr. Easton thought that 11,979,
5,500,000 gallons might safely be assumed as the lowest yield for the year. But 12,064.
Mr. Topley suggests that the water level in the chalk was rising at the time the 11,750.
measurements were taken, for the "nailbournes" broke out shortly afterwards, and, therefore, that the earliest gaugings are above the minimum, perhaps even above the mean, flow in average years. If the minimum were put at 5,000,000 gallons, it would probably be not far from the truth for last year. But Mr. Easton admitted that it had been a wet year, so that 5,000,000 gallons may be above the average for a succession of years.

But it must be remembered that the whole of the water escaping from the area in question between Dover and St. Margaret's was not ascertained. In some twenty places evidence was found of the escape of fresh water from the chalk into the sea, but the amount so escaping could not be measured. It is therefore obvious that the 11,977.
figures obtained by Mr. Easton are probably a good deal below the truth for the months of December and January last.

If, however, for the sake of comparison we assume 5,000,000 gallons as the minimum outflow of the Dover springs during 1892, this would be equivalent to a percolation of rather more than 10 inches on 12 square miles of chalk gathering ground. Mr. Easton's chief object in bringing it before us was to show how large an amount of rain-water must be absorbed by the Chalk and be ready to be given out again in springs.

We had further evidence of the large volume of water discharged by the Chalk in the same district. A little to the west of Dover a well-known spring called the Lydden Spout breaks out on the face of the cliff. This spring, when measured in 11,975.
December 1892 by the gentlemen already named, was found to be yielding between 3,500,000 and 4,000,000 gallons a day.

On the south side of the chalk escarpment numerous springs emerge, those near Folkestone and north of Maidstone being utilised for the supply of these towns.

108. Evidence was laid before us by Messrs. Easton, Whitaker, and Topley as to the large amount of water discharged by the Chalk on the north side of the escarpment, more especially where that formation passes under the Tertiary series. At Wingham, for 11,750.
example, south-west from the Isle of Thanet, certain springs were measured in December last, and were found to yield 13,500,000 gallons per day. At Wendover copious springs issue from a drainage area which has been estimated at 4·6 square miles. And all along the northern boundary of the Chalk, even where the water does not escape in strong springs, there appears to be a great deal continually discharged into the ditches and streams that traverse the flat Tertiary lands bordering the Thames. No data, however, are at present available for making an estimate of the amount of water which thus finds its way out of the chalk.

Mr. Whitaker pointedly referred to an important circumstance connected with the water of East Kent: "There can be no question of affecting higher springs, for the 11,502.
very sufficient reason that there are no higher springs to affect practically; the water over the greater part of the Kent area does not form streams or contribute to streams, but simply runs out into the sea, or into tidal rivers, so that that water is no good to anybody. It actually flows out, you may say, to waste, and thus places that area in a very different position to others."

The same witness, when asked his opinion as to the possible quantity of water that could be obtained from the East Kent area for the purpose of supplying London, replied that "undoubtedly 50,000,000 or 60,000,000 gallons, or something of that sort 11,628.
could be got—a very large supplemental supply; it might be a good deal more." Mr. Topley thinks that even a larger amount than that would be obtainable. Mr. Easton, also, though he had not formed any numerical estimate of the amount, had no doubt 11,813.
that a very large quantity of water could be obtained, and he agreed with Mr. 12,152.
Whitaker in believing that this large additional supply could be had generally without affecting surface interests.

Objections.

109. It may now be desirable that we should set out briefly the objections which have been raised to the proposals of the companies in regard to increasing the draught upon the Thames, the Lea, and the chalk formation, for the purpose of meeting in the future the growing demands of the population.

No witness appeared to protest against the taking of more water from the Thames on the ground of diminishing its volume. On the contrary, the Conservators themselves incurred considerable expense in the putting forward of engineering and geological witnesses to show that if storage reservoirs were made very much larger quantities might be abstracted. We have no doubt whatever of the "bona fides" of that board, but it must not be forgotten that a large part of its income is derived from contributions of the water companies which would cease if the Thames were abandoned as the source of supply.

Mr. Binnie, the engineer of the London County Council, may be said by inference to have objected to the Companies' suggested method of meeting the increasing requirements of London, for he said that as regards the Thames and the Lea, at
7978–9. present the main sources of supply, "they ought to be entirely discarded as sources of drinking water," on account of the pollution of their waters by the refuse of men and animals.

We are dealing elsewhere with the question of quality, but must mention this evidence here, because it may account for Mr. Binnie's not dealing specifically in any of his proof statements with the question of quantity as respects the river supplies, although at a later stage he did submit a "Report on the flow of the Thames," and we have already referred to Mr. Binnie's criticisms of the storage reservoirs suggested by Messrs. Marten and Rofe in the Upper Thames.

110. We had as witnesses the secretary, engineer, and sanitary engineer of the Lea Conservancy, and none of these gentlemen complained, except in the very mildest manner, that too much water was withdrawn from the Lea by the New River and East London Companies. The Conservators have the right to take 5,400,000 gallons a day
1482. for navigation purposes, and Mr. Child, the engineer, said, "If we take the greatest quantity we require for navigation, we take about two millions and a half gallons in 24 hours from Old Ford Lock," this quantity being calculated from the number of boats passing through this lock, which is at the lowest point where
1484. water can be taken from the Lea. When the full authorised quantity has occasionally been turned down the river, it has been for the purpose of increasing the depth in
1478–9. the Limehouse Cut. To do this, Mr. Child stated that on one occasion more than the 5,400,000 gallons a day had been used, but he went on to say that this would not
1490. occur in the future, because the Cut had been dredged, and there was now ample depth for navigation.

Major Lamorock Flower, the sanitary engineer of the Conservancy, appeared as a witness in the interest of the East London Company, and naturally made no complaint of undue abstraction of water as affecting the sanitary condition of the river.

1198. It was stated by Mr. Corble, the clerk, that "the water companies have always behaved properly. We have worked very fairly with them. We give and take as best we can."

It will thus be seen that the evidence given by the officials of the Lea Conservancy was generally favourable to the water companies, and hardly consistent with certain correspondence which was embodied in the original statement presented to us. Thus, in a letter dated the 17th March 1891, to Mr. Crookenden, the secretary of the
App. B. 17. East London Company, the following passages occur:—"I am directed by the Lea Conservancy Board to communicate with the New River and East London Water Companies on the question of the volume of water daily abstracted by them from the River Lea, and the effect of it on the navigation." * * * "It appears that in 1867, or about that year, the companies took from the Lea 38,000,000 gallons daily; the returns for January 1891 give 66,379,304 gallons. The present average daily quantity taken for the navigation for the Lower Reach is only about 1,600,000 gallons."

"The effect of the yearly increasing quantity of water taken by the companies has been a difficulty in keeping the navigation below Old Ford up to the proper head, especially at times of neap tides, and a great deal more dredging has to be done, at very great expense, to enable the traffic to be passed."

"This state of things has been very marked for some time (three years past), and particularly lately in the Limehouse Cut, where the navigation has been entirely stopped at times for want of sufficient water. The remedy for this is either for the Conservators to pass down their full statutory daily quantity or to again deepen the Cut by dredging. The latter expedient is almost out of the question, as the funds at the disposal of the Board are insufficient to meet the cost, which would be about 1,200*l.*, but before resorting to the former the Conservators, who are fully alive to the great importance of it to the companies, are desirous of ascertaining whether they will come forward and meet the difficulty.

"The traders are demanding that whenever the water is 'below head,' the Conservators shall fulfil their duty and take the full quantity allowed by the Act until the river is up to the proper level. This would mean passing down about 4,000,000 gallons more (and further if necessary) than at present taken, and this extra water, after being used for the navigation, would only be turned into the Thames and entirely lost to the companies."

"In addition to the 'traffic' question, it is frequently urged against the Conservancy that there being so much less water flowing through the lower reaches than formerly, the sewage discharged into the river is not properly flushed away and therefore a great nuisance is created, especially in the summer time."

In answer to these letters, both the companies replied that they did not desire the Conservators to refrain from taking their full statutory quantity of 5,400,000 gallons a day. The East London pointed out that there had lately been frequent floods, during which over 200 million gallons a day had passed Lea Bridge, and that if these floods did not sufficiently flush the Limehouse Cut, the statutory quantity was not likely to be of much use. They declined to contribute to the cost of dredging. The end of this correspondence was that the Conservators passed a resolution that whenever the water in the Limehouse Cut was "below head" sufficient water should be passed down for purposes of navigation not exceeding the statutory quantity. It appears from quotations already made that the Cut has since been dredged, and probably therefore no more water than before is allowed to run down to the lower reaches.

It must not be forgotten in estimating the value of the evidence furnished orally and by the foregoing correspondence that, like the Thames Conservators, the Lea Board has a pecuniary interest in the retention of the water supply from the river under its charge.

111. The views of Mr. Binnie as to the feasibility of obtaining more water from the chalk than is now taken were stated by him as follows:—

He was asked, (*Q.*) "Then passing outside the area of London itself, have you formed any opinion as to the feasibility of obtaining a much larger supply of water for London from wells in the chalk?"—(*A.*) "Do you mean in the Lea valley?" 7952.

(*Q.*) "Anywhere—in the Lea valley or anywhere else?"—(*A.*) "Undoubtedly a certain quantity of water, a certain indefinite increase of water can be obtained, and it will have to be obtained under certain circumstances. I believe if you pump anything like the quantity of water that we are contemplating for the future supply of London it must result in the lowering of the water level in the chalk districts to which you may have to resort." 7953.

(*Q.*) "You state here that the result of very careful investigations goes to show that we cannot depend upon a quantity of more than 30 million gallons a day in the neighbourhood of London from well waters?"—(*A.*) "That was the result of the inquiry at the time that the late Metropolitan Board of Works made an application to Parliament for the pumping of water. It was conducted by the late Sir Joseph Bazalgette, Sir Frederick Bramwell, Mr. Whitaker, and Mr. Easton. They calculated that they could possibly get 30 million gallons, but they only applied to Parliament for 16 millions. That scheme was very carefully considered at that time." 7954.

(*Q.*) "Did you hear what Mr. Baldwin Latham said regarding the possibility of getting an additional supply of water from the underground wells in the valley of the Lea and other valleys round London?"—(*A.*) "I did." 7956.

(*Q.*) "Do you agree with him?"—(*A.*) "I cannot say that I do. Possibly a portion of that water might be obtained, but it must be obtained at the expense of the water-level in the valleys, and the possible drying-up of the upper streams, which at present flow into the rivers in dry weather." 7959.

7963. (*Q.*) "So that your opinion as regards the amount of water available from chalk wells in the neighbourhood of London is necessarily a very vague one?"—(*A.*) A very vague one, and I think an opinion will have to be vague on anybody's part so far as I can see."

112. The witness who laid before us the most voluminous evidence in opposition to the suggestions of the Lea valley companies that they could procure from existing wells and headings, or from others to be sunk and driven, five times the quantity of water
8422–543. abstracted from the chalk in 1891, was Mr. Urban Smith, C.E. He stated that during several years past there had been a gradual lowering of the water-levels, more or less, all over a district extending from the River Colne and its tributary the Chess on the west side of the county of Hertford, eastwards by the watersheds of the Gade, Bulborne, Ver, Lea, Mimram, and Beane, and in a less marked degree of the Rib, Ash, and to some extent the Stort. That in his opinion this lowering was not due to a decline in the amount of rainfall, nor to extended land drainage, as was sometimes asserted, but to the constantly increasing pumping from below the line of saturation in the chalk and through artificial vents being made by means of speculative or other borings.
App. C. 38. That the water-levels had actually been depressed as suggested, Mr. Smith said was proved by—

The reduction in the flow of springs;
The drying-up of water-meadows;
The drying-up of watercress beds;
The gradual lowering of water in wells;
The decline in the volume of rivers;
The lowering of water in boreholes (made) into the chalk;
The drying-up of river heads.

That the depression is not due to diminished rainfall, Mr. Smith essayed to show by a summary of records of the mean fall in the county from the 1st October 1800 to
App. C. 38. 30th September 1890, prepared by Mr. Hopkinson. The sixth column in this summary gives the annual mean of each decade, and he deduces from these the annual mean for the whole 90 years' term, which works out to 24·89 inches. As compared with this figure, the mean for the years 1870 to 1880 was 28·602, and 1880 to 1890 26·623, the first being 15 per cent. and the second 7 per cent. above the mean. Mr. Smith admits that the winter rainfall (during which most percolation takes place) of the three years prior to March 1891 was somewhat below the mean, and that this might account for some lowering of the water-levels, but he points out that these years followed a six years' wet period; and, further, that the gradual depression had been perceptible sometime before 1891.

Mr. Smith contended that the effect of efficient agricultural land drainage was not, as many supposed, to intensify floods, but, on the contrary, by drying the ground between the surface and the drains to render it more absorbent; so that, instead of running rapidly off the surface, the water was retained and discharged gradually, thus diminishing floods and increasing the flow at other times. Extended draining could not, therefore, he said, be the cause of the depressed water-levels.

He thought the pumping of water from wells in London had to some extent affected its level in Hertfordshire, but only slightly, because of the difficulty with which it traverses the highly compressed chalk under the London clay. He admitted also that the increased draught from wells sunk by local authorities in the county had probably lowered the water somewhat; but his strong point was that the continuous pumping by the water companies in the Lea valley was gradually lowering the surface of the water in the chalk above the points of pumping, and markedly right at the heads of the surface streams. He says, in fact, therefore, that in the Colne district there is distinctly appreciable at the present time the effect which Mr. Latham testified had actually resulted from over pumping at Croydon.

Mr. Smith frankly admitted that the evidence upon which his deductions were based (and which is set out in great detail in his statement) was of a somewhat vague and not quite reliable character, consisting in great part of the general impressions
8427. of farmers and millowners and labourers, unsupported by many solid facts and figures. He nevertheless adhered to his opinion under examination that both the surface and underground water levels in Hertfordshire had been depressed of late years, and he believed this was due to the operations of the two Lea companies, because their constantly increasing pumping was the potent disturbing factor which had

been introduced during the period under consideration. Mr. John Hopkinson, F.G.S., was called for the Hertfordshire County Council, and laid before us extensive tables of the rainfall of the county and elaborate analyses of percolation and evaporation, App. C. 37.
as deduced from the gauges at Nash Mills, Rothamsted, and Lea Bridge. His ultimate deduction from these figures was, that the mean annual rainfall of the county for a long term might be taken as 26 inches, out of which 6·76 inches, or 26 per cent., percolated into the ground, and 19·24 inches, or 74 per cent., evaporated. That for a three years' period of abnormally dry weather the percolation might average not more than 4 inches per annum, and on the other hand it might for a similar term rise to 9¾ inches. It is manifest that differences of this degree may have a very marked effect upon the level of the plane of saturation in the chalk, and consequently upon the length of streams whose appearance on the surface is due to the saturation of the ground forming their beds.

113. Mr. Hopkinson stated that he had observed the River Colne in many varying conditions as regards its level and volume, and, referring especially to its course through North Mimms Park, expressed the opinion that some abnormal cause had been operating of late years which resulted in the drying of its channel more completely and more frequently than mere seasonal variations had previously done, and that this cause was the pumping by the water companies in the Lea Valley. Mr. Hopkinson, however, adduced no facts in support of his assumption.

114. Sir John Evans, Vice-President of the Royal Society, &c., &c., and Vice-Chairman of the Hertfordshire County Council, supported Mr. Urban Smith's contention in a very positive and emphatic manner. Thus, in the 13th paragraph of his printed App. C. 53.
statement of evidence-in-chief, he said, "The springs, rivers, and water levels" (of the County of Hertford) "are already being affected by the pumping from the chalk of 11,000,000 gallons daily by the New River and East London Companies," and further: "If these companies pump as they suggest to the Commissioners they can in the future 55 million gallons, or *five times* as much as now, the effect will be most disastrous to the water supplies of the county; and in years like 1864 and 1874, when the total discharge of the River Lea was little more than 60 million gallons daily, absorb nearly the whole of that river."

In support of the first part of this statement, Sir John Evans said that he had observed the diminution of the water supplies in the county. Thus, last year (he said) "the River Ver rose 5 miles short of its usual point, and the River Gade 3 miles. Watercress beds were dried up, and although after a very wet six months, from October 1891, to March 1892, there was a good supply of water in the county, it is now rapidly falling away."

For confirmatory evidence of the fact that the water levels were being depressed, he depended upon the statement prepared for the county by Mr. Urban Smith; and his correlation of the depression with the pumping by the water companies was a theoretical deduction. Being asked (*Q.*) "But I quite fail to see what evidence there 9978.
is that the pumping which has been going on, would for the time that it has been going on and the quantity taken out really touch these waters."—(*A.*) "I say myself I do not see that you can get any absolute physical proof that it has, but theoretically—and I think the theory is absolutely true—the pumping must of necessity be supplied by water, which otherwise would have found its way into the river." (*Q.*) "Then it is a matter of theory with you?"—(*A.*) "It is a matter of 9979.
theory, but I believe in that theory so strongly that I regard it almost as a matter of fact."

115. It may be mentioned here that Mr. William Whitaker, F.R.S., one of the oldest and most experienced members of the staff of the Geological Survey Department, made the following remark in the statement prepared prior to his first appearance before us:—"A large chalk area is already under contribution for the public supply of App. C. 48.
London, besides which private supplies also get a considerable amount of chalk water, and, indeed, have already much lowered the water level under the central part of the Metropolitan area."

"The public supplies from wells are got by three companies, the Kent on the south, which gives only a well supply, the East London and New River on the North, which supplement their river supplies with well water."

"The first is equal to the supply of its district and may be extended to the eastward as the population increases."

"The other two have, by works done or in progress, secured practically as much as can safely be taken from the basin of the Lea without seriously damaging the river, especially in its upper waters."

While giving evidence to us Mr. Whitaker stated that if the New River and East London Companies together abstracted 30 million gallons a day from wells in the Lea Valley they would lower the outflow of the higher streams; he said, "I do not
9490. see how you can possibly take a large amount of water out of a chalk reservoir and not affect the streams." He admitted that he had no information as to the actual effect that pumping had had upon the streams up to the present time, and could only refer for facts to the evidence given on behalf of Hertfordshire. The general drift of
9494–7. his evidence was that the pumping in the Lea Valley had not hitherto been carried on to such an extent in respect either of time or quantity as to enable anyone to judge conclusively of its effect on the distant streams. He was under the impression that more was now being pumped than actually is the case; that a take of 30 millions a day from the Lea wells would be injurious, and he was quite clear that if the supplies now obtained from the Rivers Thames and Lea were stopped, and all the water required for London taken from the chalk by pumping (which to the extent of
9541–2. 200 million gallons a day he believed might be done) all the contributory surface streams would be practically dried up. Mr. Whitaker added no facts helping us to correlate present pumping in the low part of the Lea with depression of the plane of saturation in the higher parts of that valley or of the Colne.

116. We now turn to the consideration of the independent inquiry into the facts carried on by Mr. Middleton. We attached so much importance to this branch of the subject that we instructed him to visit the localities said to be affected and thoroughly to
App. H. 1. investigate the facts. We have printed his report, which deals exhaustively with the whole subject, in the Appendix. Amongst other matters referred to him for special inquiry, he was directed to sift the evidence given by Mr. Urban Smith in support of the three following assertions, viz.:—

1. That many of the rivers of the county rose considerably below the point at which they had their source 20 years previously, and were much reduced in volume.
2. That the volume of many natural springs was much diminished.
3. That the water levels of the county were materially lower than in the past.

Upon these three points Mr. Middleton has made personal inspections and inquiries within the watersheds of the Colne and Lea and of their respective tributaries, taking evidence as to the past and present sources and courses of the rivers themselves, as to watercress beds, the yield of springs, the fluctuations of the water levels in wells, and as to the water power available at different periods at the many mills located upon the streams. His report deals at length and in great detail with 11 streams, many wells, watercress beds, and springs, and with 45 mills, and it will only be necessary here to quote the following passages which summarise sufficiently the general conclusions at which he has arrived:—

Wells.—"There is no reliable evidence of the permanent depletion of any well except from local pumping, and the evidence regarding the drying up of certain wells is confined (except as regards local pumping) to such as were sunk in a high-water season, and were not sufficiently deep to meet the seasonal fluctuations, or to such as are not supplied from the general area of the chalk basin."

Sources of Rivers.—"There does not appear to be any evidence of the permanent lowering of the source of any river. In the cases of the Rivers Colne, Lea, Mimram, Beane, Rib, and Quin, the sources are all clearly defined, and have not altered in position at all. In the cases of the Rivers Bulbourne, Gade, and Ver, the point at which they rose has always fluctuated considerably, and there is abundant evidence to show that, in the cases of the Rivers Gade and Ver, at any rate, there have been previous occasions when they were as dry as in 1891, and an examination of the well sections and of the seasonal fluctuations to which they are subject will indicate that such must have been the case."

117. The Ver and the Gade were specially mentioned by Sir John Evans as having risen in 1891 respectively 5 miles and 3 miles short of their usual sources. Upon these rivers Mr. Middleton says: "the evidence (given before the Commission) states that the Ver has its source partly to the north and partly to the north-west of Kensworth Lynch, but that in 1891 it was dry down to Redbourn a distance of 5 miles, the

inference being that previously to 1891 the river had always risen further north than Kensworth Lynch."

"An examination of the locality shows that this statement cannot be supported in this sense; the bed of the stream has a gradient which is only a little steeper than that of the dry weather line of saturation in the chalk-water system, and a comparatively small reduction of level in the water, and consequent flattening of the gradient in that system, serves to dry a proportionally extensive length of the river."

"It is quite clearly proved from the evidence of the wells at Kensworth Lynch that the River Ver never did rise either at this point or above it except in 1883, and at some previous period of (probably) equal rainfall of which there is no record."

Again, "It is stated in evidence that a spring formerly rose at Kensworth Lynch, and was one of the principal sources contributing to the supply of the River Ver."

"The evidence of the wells proves conclusively that there never was any permanent spring at Kensworth Lynch. In times of high flood a gravel pit used to overflow, as did the wells, and the whole of the land became surcharged with water under those conditions, but there was no spring, and if there had been it must have been upheld by a fault, and could not have been affected by the level in the chalk water supply below any more than pumping below a weir could affect the supply above it."

Mr. Middleton visited the River Bulbourn on 13th September 1892 (a period of the year when springs are low), and states that at that time its source was very much higher than it had been in 1891, although it was then 683 yards below the source of 1849, 853 yards below that in 1877, and about 1,000 yards below that of 1883.

He explains with regard to its abnormal lowness in 1891 that the Grand Junction Canal Company obtained leave to pump from their well at Cow Roast under the plea that if they did not do so they must stop working the canal, and that this pumping, combined with that of the Chiltern Hills Water Company, the Berkhampsted Water Company, and a brewery, would have a considerable local effect upon the river. Further, that if there has been any permanent depletion of the river, or of the springs, it is due to this local pumping and to the extension of water-cress beds, by which a much larger area of gravel is exposed and freer exit given to the water, and to the introduction of tube-wells, which, if allowed to run constantly, would discharge at least one million gallons a day.

118. Again, Mr. Middleton says, "I am unable to find in the whole of the evidence and in the arguments produced a single item which is at all strongly in favour of the theory of permanent depletion, while there are many most convincing arguments in support of the theory of seasonal change.

"Taking the oral evidence as a whole, it is shown that the source of no river which has been examined is at the present time, or was in 1891, at a point lower down in the valley than it had been at some previous period before 1875, and Mr. Topley says 8620.
there was a belief in the depletion of the rivers, &c. in or about 1868, a time of great drought," and it may be added, a time long anterior to the date at which the Lea Valley Companies began to pump any material quantity of water.

"At many of the mills the evidence of depletion is clearly disproved, while in others it is negative, or the complication of machinery and the altered conditions of working render the value of the comparisons drawn of exceedingly doubtful import, to say the least.

"An examination of the water contour map and of the well sections shows that with very few and trifling exceptions, which can be accounted for by local circumstances, the laws of gradient and direction are strictly followed, and the level of the water in the chalk basin is below that of the rivers, even in times of high-water seasons, down to points on the rivers themselves far below the places where they are said to have taken their rise in former years, and that even if the rivers had been depleted at those points, abstraction of water from the chalk basin could not be responsible for the loss.'

Mr. Middleton concludes his report by reiterating his opinion (already referred to) in the following terms: "For the reasons recorded above, with the information derived from the tables of rainfall and percolation and from the river gaugings, along with the general evidence, I am of opinion that there is no proof of any permanent depletion of any river, well, or spring, except from local causes, while there is conclusive evidence that the changes recorded, where not produced by local pumping or the

undue extension of watercress beds, are seasonal, that they have occurred to at least as marked a degree in years gone by, and before 1875, and that they will occur again."

119. After full consideration of the evidence given by the companies' engineers and the professional witnesses called in their support, and by the representatives of the county of Hertford, and of the report prepared for us by Mr. Middleton, we are of opinion that we are not justified in believing that the pumping by the New River and East London Companies has actually and in fact produced as yet a permanent appreciable depression of the water levels in Hertfordshire, and the upper part of the Lea Valley, although such pumping may temporarily affect to some extent the height of water in wells in the immediate neighbourhood of the companies' works. That these companies can continue to increase the quantity pumped from the chalk with equal immunity until it has reached five times the present "take" we are not prepared to say, as will be seen later on.

We think there can be no doubt, although Sir John Evans does not agree, that water is constantly passing in considerable volume from the north and north-west to the south-east under the pumping stations in the Lea Valley, and ultimately finding its way into the bed of the Thames some distance below London.

We have, however, been unable to procure any evidence whatever as to the quantity so discharged, and this is not to be wondered at, for in the nature of things it is practically immeasurable. If this leakage could be entirely stopped, the companies might pump its whole amount less the quantity required in the tract of country intervening between their wells and the river. It is not unreasonable to assume that the leakage is to some extent diminished on account of the pumping; although to this proposition also Sir John Evans is not prepared to assent. If he is right, then the quantity pumped is "plus" the leakage, and a time must come, as pumping increases, when the combined draught upon the water in the low levels of the chalk reservoir must tend to depress the surface of the plane of saturation in the higher parts of the water-shed.

120. Mr. Baldwin Latham's proposition that if more water is abstracted from a given area than percolates into that area, the then water levels will be lowered both above and below the points of abstraction, is incontestable. To apply this axiom to the Lea case so as to be able to estimate with absolute precision how much may be pumped from the chalk is most difficult, if not indeed impossible. To do it we must be able to determine :—

1. The boundaries of the underground watershed and to measure its area;
2. The respective areas of bare chalk, of impermeable superimposed drifts, and of more or less pervious deposits;
3. The depth of rainfall percolating into the ground upon each of these areas, or flowing off some of them into the others, and the mean percolation over the whole;
4. The quantity of water which, having percolated into the chalk in the higher districts, finds its way into the River Lea again before it reaches the tertiaries;
5. The quantity of water uncontrollably flowing out of the area by natural outlets and withdrawn legitimately by artificial means.

If these factors were determinable we could then decide how much the companies might pump without doing damage in a year of mean percolation and, what is more important, in a year of minimum percolation. We use the latter phrase advisedly because we are satisfied that it is impracticable to calculate with any degree of accuracy to what extent the super-storage of a wet year can be relied upon to supplement the defect of a following dry year.

121. The geologists who have given evidence on both sides have agreed in estimating the mean annual percolation into bare chalk at 10 inches, but Mr. Hopkinson and Sir John Evans have pointed out that on the average of three consecutive dry years it may be something under 4 inches a year. Precise calculations can be made in respect of surface water supplies, because the storage reservoirs are of known capacity and as a rule have no unascertainable leakage; but this cannot be done with similar exactitude in the chalk.

If we were able to accept the opinion of one of the geological witnesses, Mr. Boyd Dawkins, this is a matter about which we need not trouble, because according to him there is held up in the body of the chalk an almost inexhaustible store of water which may be reckoned on to equalise the varying rainfalls and percolations of alternating seasons. We cannot, however, accept this theory; on the contrary, we are of opinion that for practical waterworks' purposes the only available water is that

which is for the time being present in the more or less open spaces between the solid masses, be they called fissures, joints, cracks, or interstices. We believe that when these are depleted the water which is held in the mass by capillarity gets out, if at all, with such extreme slowness as to be to all intents and purposes useless. This being so, we must make the best estimate that is possible on the bases available of the quantity of water which gets into the chalk in the Lea Valley, and can be recovered for the supply of London only by pumping.

122. The first factor is the area of the collecting ground, and the figures we propose to adopt are derived from the evidence of Mr. Topley, coupled with information got together by Mr. Middleton in his special investigations. Mr. Topley gives the area above the point on the River Lea at which the Chalk goes under the Tertiaries; and Mr. Middleton that above Feilde's Weir, and fortunately these two points are practically identical. After considering some slight divergence between their figures and between those which were given by Mr. Nathaniel Beardmore before the Duke of Richmond's Commission in 1867, and making an independent measurement ourselves, we have come to the conclusion to call the area above Feilde's Weir 422 square miles.

Considerable trouble has been taken by both Mr. Topley and Mr. Middleton in endeavouring to determine whether or not the underground shed to the wells in the Lea Valley is or is not co-extensive with the surface shed. They are both of opinion that portions of the Colne drain into the Lea; the most noteworthy case being that at North Mimms, which has already been described. Mr. Topley thinks, too, that a 1110.
few square miles of the Cam also yield water to the Lea, but there are on the other hand places where the underground parting line is inside the surface ridge; and we have therefore decided on adopting 422 as applying underground as well as on the surface.

This may be divided as follows:—

	Sq. miles.	Sq. miles.
Bare chalk	95	
Chalk covered with permeables	50	
		145
Chalk covered with mixed beds partly permeable and partly impermeable	60	
Impermeables draining on to the chalk	146	
Impermeables not draining on to chalk	71	
		277
Total		422

123. From Mr. Symons' evidence it may be taken that the mean annual rainfall of a App. C. 9.
long term on the 422 square miles above Feilde's Weir is 26·5 inches, that the average of three consecutive dry years is 22·8 inches, and the fall in the driest year 19 inches.

Mr. Hawksley stated with regard to the Thames watershed area that the average App. C. 27.
annual evaporation would be 16 inches, and in the driest year 14. These figures are equally applicable to the Lea, and on the average of three consecutive dry years something less than their mean, or 14·8 inches, may be assumed as a close approximation to the fact. Deducting this from the 22·8, 8 inches will be left to run off into the rivers or to percolate into the ground. Of that which gets into the ground a portion is returned to the river after passing through the Chalk above Feilde's Weir, and another portion, descending deeper, is conveyed under the Tertiaries to a lower part of the valley.

We accept Mr. Hawksley's view that in the driest year 4 inches of the rainfall would flow off by the river, and on the average of three consecutive dry years it is manifest that this amount would be somewhat increased, and to what extent was shown by Mr. Beardmore in 1867. He stated that for the three dry years, 1862–3–4, with a mean annual rainfall of 21·86 inches, the yearly discharge at Feilde's Weir, including the "take" of the Water Company above, averaged 80·8 million gallons per day; that in 1863–4–5 the mean rainfall was 22·88 inches, and the average discharge 75·6 million gallons. Reckoned upon the now accepted area of 422 square miles (Mr. Beardmore having called it 444), the discharge of the first of these terms represents 4·79 inches flowing off, and the second 4·48, or a mean of 4·63.

Deducting 4·63 from 8 we get 3·37 as the quantity left to percolate into the ground and pass partly under the Tertiaries, being thus available for the pumping stations either above or below Feilde's Weir. From Mr. Hopkinson's tables we find that in three consecutive dry years the percolation at Nash Mills through 3 feet of soil with grass growing on the surface averaged 3·75 inches, and at Lea Bridge 3·63 inches per annum. At Nash Mills through 3 feet of chalk (the usual thin soil) and grass, the percolation in a similar cycle averaged 5·78 inches.

We are of opinion that these artificially filled gauges—certainly those with chalk—are likely to pass more water than would percolate through similar material in its undisturbed natural condition. Bearing this in mind, and having regard to the classification of the superficial beds within the watershed as given above, we think the product of 3·37 inches over the whole 422 square miles may fairly be relied on as obtainable by pumping in the lower part of the Lea Valley, including the Chadwell Spring. This will amount to 3,303,915,648 cubic feet per annum, or, say 56 million gallons per day, and is, we believe, the full quantity which can be abstracted by the two London companies and others without prejudicially interfering with the surface and underground water supplies higher up the valley on the average of three dry years.

124. But it must be noted that, although this quantity might be taken without injury to those above the highest of the companies' pumping stations, some lowering of the water levels will undoubtedly take place in chalk wells in the immediate neighbourhood of those stations—in which case the companies should have the obligation put upon them of re-ensuring these supplies on fair terms—and that the districts below the lowest of the stations will to some extent be deprived of their underground water.

We think it is unlikely, however, that all leakage past the works could be stopped, and to the extent that it was not, the quantity available for the companies would be less than the 56 millions. Mr. Baldwin Latham said there was "nothing in the Lea
7621. Valley below the points of pumping to be materially affected." This may be so, but
9078–80. it has been suggested by witnesses appearing for the companies (and others) that the
9109–19. water which passed beneath their works might have its ultimate outlet into the Thames
11,593. near Woolwich, or opposite Erith, or even further to the east, that is, some distance
9687–99. 11,862–70. outside the drainage area of the River Lea ; and with this view we are, to some extent, in accord. We are not, however, of the opinion that much of the water found in the neighbourhood of Grays (which was frequently mentioned in evidence) is likely to come from the area with which we are immediately concerned, viz., the 422 square miles above Feilde's Weir. There are considerable tracts of exposed Chalk and Chalk covered with permeable material in the more immediate neighbourhood, and, it may be that water passes into the Chalk on the north side of the Thames from the great outcrop in Kent on the south side ; and in addition there is the River Roding.

125. On these grounds, and taking also into account the evidence of Mr. Topley, that in the lower part of the Lea Valley near Lea Bridge the river gravels rest directly on the sands of the Tertiaries, and that a considerable quantity of water is obtainable from that source, we are of opinion that there need be little fear that the districts south and south-east of the companies' most southerly works will be prejudicially affected if on the average of three dry years they take all the water their works can intercept out of the 56 millions.

In the driest of the three years, especially if it came last in the cycle, 56 millions would clearly not be obtainable, probably not more than 47, but we believe that the companies, after providing reasonably for all below them, might, under the worst conditions, reckon on obtaining 40 million gallons a day.

This being so it is manifest that we cannot agree with the companies' witnesses, that an aggregate quantity of 58 million gallons a day may at all times be pumped from their underground sources. During a succession of wet years no doubt more than 56 millions will be available for the companies and their neighbours and the district below them, but this would be of little use as their means of supply must be equal to the demands upon them in the driest times.

126. In coming to the foregoing conclusions as to the quantity of underground water obtainable in the Lea Valley by pumping we are declaring in a very practical way our disagreement with and dissent from the opinion expressed by two witnesses of very high standing, viz., Sir John Evans and Mr. Whitaker, the former of whom expressed himself in a very emphatic and decided way, and the latter with some caution and hesitancy. Sir John Evans is a prominent advocate of the "cistern

theory" as bearing upon the presence and movement of water in the chalk. He said: "If you look upon the whole water in the chalk as one continuous body of water separated by blocks of chalk like water in a cistern would be if you had a number of pebbles in it, and assuming that you had a small tap running away from the cistern showing the amount of leakage, then I think you will see that anything you pump would affect the level of the water in the cistern, and would not stop the leakage from the bottom of it." Again: "My view of the water in the chalk is, as I said before, that it is as it were in a cistern with blocks of chalk or anything else in it, that any fresh water coming in from above, after a certain portion of it has been diverted for vegetation and by evaporation, will flow off the surface of that cistern as an overflow, and that will take place even if there is a little leakage from the bottom, provided that the amount coming in is greater than the leakage; but any amount of pumping as long as that leakage exists, will take the water from the top of the cistern and prevent its overflowing, and will not stop the leakage from the bottom." 9880-1.

We are of opinion that the analogy of a cistern is inaccurate and misleading when used in relation to streams at a considerable distance from the points where pumping is carried on. A waterworks well is in itself a typical cistern; the pumps are not unfrequently submerged many feet, and when pumping begins it is the bottom water that is withdrawn, and in consequence of losing its support the upper water is proportionately lowered. Within the enclosing sides of the cylindrical well the water falls vertically, and with a level or horizontal surface. But in addition to this vertical and horizontal lowering in the open well, there goes on simultaneously a lowering of a different character in the chalk around the well.

127. Immediately adjoining and outside an unlined chalk well, the water lowers *pari passu* with that inside, but the same horizontal plane is not continued outwards. The water cannot pass through the crevices in the chalk to the well without a certain amount of fall or slope, this being necessary to overcome the friction of its passage. Hence the surface of the water in the emptying chalk rises from the well in all directions at a gradient more or less steep in relation to the openness or closeness of the passages. These slopes will nowhere probably form a symmetrical or regular cone-shaped depression having the well as its centre, but slopes at varying angles modified by circumstances are undoubtedly required if the supply to a well is to be maintained whilst pumping is going on.

It is only necessary to follow out this idea to a distance of miles from the well to realise clearly that the cistern theory is untenable. In the open well the upper water is supported directly by that below it, and when the support is removed the surface is immediately and vertically depressed. Out in the body of the chalk the upper water is only partially supported by that below it, and mainly by the chalk in and upon which it lies and flows, and this being so the analogy of a river is much more apt and accurate than that of a cistern. Mr. Baldwin Latham and other witnesses were therefore more nearly right than Sir John Evans when they said that pumping from a well tapping an underground stream flowing in a known direction mainly affected the water below the well, and had little effect on that above the well.

128. For these reasons it is not surprising that Mr. Middleton has found no confirmation of the assertions that the water in the upper parts of the Lea and Colne valleys has been permanently depressed through the pumping done by the New River and East London Companies. Such a depression is not likely to take place, in our opinion, until the quantity which is being pumped out, and naturally leaks out of the chalk, is in excess of that which is put in by the percolation of a part of the rainfall. What this quantity will be in a cycle of three consecutive dry years we have already ventured to estimate at 56 million gallons a day, and in the driest year at 47 millions.

In addition to the negativing of the evidence of the Hertfordshire witnesses, by the investigations of Mr. Middleton, that the companies' pumping has already lowered the water levels in the upper valleys, it may be urged that the facts and figures we have had laid before us in regard to that pumping go far to confirm the river theory and destroy the cistern theory.

129. Let us describe the circumstances somewhat in detail.

The main valley of the Lea from Ware to the Thames falls, broadly speaking, from north to south. Just below the bend of the river to the west at Ware, the New River Company takes water from the chalk directly by the Chadwell spring, the Broadmead

well, and the Amwell End well. The spring is situated 21 miles due north from the left bank of the Thames at Wapping, which is the nearest point at which the chalk water has an outlet at sea level. At varying distances apart down the valley, and (with one exception) close alongside the artificial "New River," this company has 11 other wells, the most southerly being at Campsbourne, 15¼ miles south of Chadwell.

The East London Company has four wells all close by the River Lea, and from two to three miles east of the New River, the most northerly being at Waltham Abbey, 8½ miles south of Chadwell, and the most southerly at Lea Bridge, 8¼ miles still further south.

The height of the ground surface at Chadwell is 112 ft. above Ordnance datum, and at Lea Bridge 23 ft., showing a fall of 89 ft., and the spring issues at 110·5 ft., whilst the "rest" level of the water in the Lea Bridge well is 10 ft. below Ordnance datum, showing a fall of 120½ ft. At the Walthamstow well, which is about one mile north of the Lea Bridge, the "rest" level is stated to be 15 ft. below Ordnance datum, that is several feet below low water in the Thames. There can be little doubt that the rest level is depressed at the south end of the Lea valley, because of the lowering of the water by exhaustive pumping under London, although this lowering has not taken place to nearly so great an extent in the east as in and about the city, and further to the west, where it is now 100 ft. or more below Ordnance datum.

Eight out of the 13 wells of the New River Company have boreholes carried down to depths varying from 26 to 912 ft. below Ordnance datum. Nine of them have headings, but of no great length, the longest being 450 ft. At the East London Company's Chingford well, a boring is taken down to 414 ft. below Ordnance datum; at the Waltham Abbey and Walthamstow wells respectively 512 and 520 ft. of headings have been driven, and at Lea Bridge 6,800 ft.

From Chadwell spring down to the Cheshunt well, there is a fall of 28 ft. in the surface of the rest level of the water in a distance of 7 miles, or 4 ft. per mile. Then there is a fall of 39 ft. from Cheshunt to Waltham Abbey in a south-easterly direction in 2⅛ miles, or 18 feet in a mile, and a fall of 38 feet from Cheshunt to Hoe Lane in a southerly direction in 3½ miles, or 11 feet in a mile. Then from Hoe Lane to Walthamstow, a distance of 6 miles, in a direction slightly east of south, the fall is 55 feet, or about 9 feet in a mile. Proceeding in a south-westerly direction, through Hoxton to the City, we come, at 2½ miles from Lea Bridge, to a well with a rest level of 90 feet below Ordnance datum, and at four miles away to many wells where it is 100 feet. The first of these shows a gradient of 32 feet in a mile, and the others 22 feet.

130. There are some anomalies about these levels and gradients, notably the steep fall from the Cheshunt well to the Waltham Abbey well, but it is pretty clear that from Chadwell to Cheshunt the natural fall has not been affected by the depression to 100 feet below Ordnance datum under London. For from Chadwell to the Thames at Wapping a regular gradient from the fixed spring level to mean tide would give about 5 feet in a mile, as against 4 feet, which now prevails for the first seven miles south of the spring. From Cheshunt southwards it appears to us there is evidence of the effect of the excessive pumping under London, and this was to be expected, for all we have heard goes to show that more water is being pumped there in a given time than can pass through the chalk (highly compressed as it is by the overlying tertiaries) in that time. The effect of pumping under these conditions is to maintain a permanently low level of the plane of saturation, which affects the slope of the water for 10 or 12 miles north of London. But no such conditions as these prevail from Cheshunt upwards.

In the nine wells of the New River Company above Cheshunt the rest level of the water surface coincides practically with the natural gradient line of 4 to 5 feet per mile, and has not altered since the time at which the wells were sunk. The Chadwell spring, too, is flowing out now at the place and level it did 250 years ago.

The Cheshunt well was sunk in 1846, the Amwell End and Amwell Hill wells in 1848, the Hoddesdon in 1864, the Turnford in 1867, and the others in later years down to 1881. The most modern of these has therefore been in operation for 12 years, and from all of them water has been pumped in constantly increasing quantities year by year. Evidence was given that, although the water level was lowered in these wells by pumping to depths varying from 17 feet at Broadmead to 157 feet at Turnford, there was very little effect produced by pumping *inter se*, and that on pumping being stopped the water rapidly rose again to the normal rest level.

As no permanent lowering has as yet taken place similar in character to that which has occurred under London, and as temporary depressions are so speedily recovered, it is difficult to conceive how any effect whatever can have been produced in the higher valleys as spoken to by Sir John Evans, Mr. Urban Smith, and others; both facts and theory fail in our opinion to support their contention. If there had been any permanent lowering of the water levels at the pumping stations, it might have been urged with some force that a corresponding, if not an actually similar, depression must have taken place all along the plane of saturation, but as such permanent lowering has not occurred there is no ground whatever for attributing depletion above to this cause.

131. *Kent Wells.*—From the south side of the river no evidence was submitted in opposition to the Kent Company in respect either of their present take of water, or of their proposals in the future.

Conclusions as to future available Supply within the Watersheds.

132. We may now complete this section of our report by stating the conclusions we have arrived at on the question of quantity, as qualified by the terms of the reference.

From the River Thames.—In estimating the quantity of water which may be obtained from the Thames we have given full consideration to the topographical, meteorological, geological, statistical, and engineering evidence which has been laid before us by the representatives of all the parties, although we shall now quote figures only from a few of the proofs. The area within the Thames watershed down to Kingston was assumed by the Duke of Richmond's Commission (on evidence then received) to be 3,676 square miles, and this figure has been adopted by Mr. Hawksley, Mr. Baldwin Latham, and others in the present inquiry as the area down to Teddington Weir.

Both Mr. More and Mr. Binnie have made new and independent admeasurements, and compute this area respectively at 3,766 and 3,789 square miles, and as Mr. More App. B. 6. (being engineer of the Thames Conservancy) may be assumed to possess the fullest acquaintance with the shed, we propose to adopt his figure. From Mr. Topley we App. C. 41. accept 3,548 square miles as being approximately the area above the intakes of the water companies.

133. Mr. More has put in gaugings of the discharge of the Thames at Teddington App. B. 6. for the nine years 1883 to 1891, which it will be convenient to reprint here, with an added column showing the rainfall, for easy reference in the calculations which are to follow:—

Year.	Total Quantity of Water abstracted by the Water Companies.	Volume of Discharge at Teddington Weir, as gauged by the Thames Conservancy.	Total Flow of the River Thames. Col. 2 + Col. 3.	Average Annual Rainfall on Thames Basin, above the Intakes of the Metropolitan Water Companies.
1.	2.	3.	4.	5.
	Gallons.	Gallons.	Gallons.	Inches.
1883	26,197,000.000	659,657,000,000	685,854,000,000	28·41
1884	29,946,000,000	330,648,000,000	360,594,000,000	22·90
1885	29,654,000,000	399,130,000,000	428,784,000,000	29·15
1886	30,350,000,000	544,786,000,000	575,136,000,000	31·07
1887	32,154,000,000	390,296,000,000	422,450,000,000	21·32
1888	30,280,000,000	427,656,000,000	457,936,000,000	28·45
1889	31,419,000,000	437,059,000,000	468,478,000,000	25·64
1890	32,876,000,000	261,916,000,000	294,792,000,000	22·81
1891	35,185,000,000	472,228.000,000	507,413,000,000	33·31
Totals -	278,061,000,000	3,923,376,000,000	4,201,437,000,000	243·06
Average of the above 9 years -	30,896,000,000	435,931,000,000	466,827,000,000	27·01

In the third column of this table the average yearly discharge of the nine years at Teddington is given as 435,931,000,000 gallons. But this quantity is subject to some correction, for we found on investigating the details of the gauging arrangements at Teddington that it was desirable to check the results by simultaneous measurements at Molesey and Sunbury weirs, and having entrusted this work to Mr. Middleton and App. H. 4.

considered his report we accept his opinion that Mr. More's quantities should be increased by 7 per cent.

To the	435,931,000,000 gallons
we therefore add	30,515,170,000 "
making	466,446,170,000 "
and again to this must be added the average quantity taken by the companies, viz.:—	30,896,000,000 "
giving a grand total of	497,342,170,000 gallons.

Divided by 365 this gives a daily average of 1,362,581,288 gallons.

But during the nine years in question the rainfall averaged only 27·01 inches as compared with 28·50 which Mr. Symons gives as the mean fall of a long term upon
App. C. 9. the watershed. We therefore increase the daily volume to 1,437,747,750 gallons, raising it in the ratio of 27·01 to 28·50. This quantity must, however, be reduced in the proportion of the area above Teddington, viz., 3,766 square miles, to that above the intakes, which is 3,548 square miles, thus bringing down the net daily quantity to 1,354,521,778 gallons.

This, we believe, is a very close approximation to the average daily flow of the Thames down to the waterworks intakes during a long series of years, and we will call it in round figures, 1,350 million gallons. The average daily discharge of three consecutive dry years we estimate at 1,120 million gallons and of the driest year at 900 million gallons.

134. These being the facts we are of opinion that by the construction in the neighbourhood of Staines of reservoirs of adequate capacity into which water shall be pumped and stored in times of excess to be used in times of deficiency, at least 300 million gallons a day may be obtained for the supply of London. We believe this can be done without taking in the more turbid of the flood waters and without injuriously diminishing the volume of the river below the point of abstraction. To ensure the best results in both these respects the taking of the water should be subject to strict regulations laid down by Parliament.

The water allowed to be taken from the river should, in our opinion, include any water which may be pumped from the gravel beds in the vicinity of the river.

135. *From the River Lea.*—The available drainage area of the Lea above the lower
12,196. intake of the East London Company is stated by Mr. Bryan to be 460 square miles, and
13,809. the mean rainfall upon it is stated by Mr. Symons to be 26 inches. No gaugings of the discharge have ever been made at or below the intakes, but they have been kept for many years at Feilde's Weir, which has above it (as before stated) an area of 422 square miles. From this area we have made out that on the average of three consecutive dry years 81 million gallons a day will flow off by the river.

651. We have had no definite evidence as to the capability of the district *below*, but from some remarks of Mr. Bryan's, we judge that he does not calculate upon getting an additional quantity proportional to the whole area, and we shall probably be safe in calling the total available quantity 85 million gallons. Of this the New River Company draw 22½ millions direct from the river above Ware, and the East London Company have at times drawn 37 millions, but in their statement set out in paragraph 88 they claim to take only 30. Dealing with the river as a whole this abstraction is, in our opinion, too great with the storage now in existence, but if other reservoirs were constructed adequately increasing the storage capacity on well recognised lines the taking of 52½ million gallons a day may be continued.

The taking of the water should be under regulations similar in character to those suggested for the Thames, viz.: the first flush of floods to be rejected and in dry weather no water to be abstracted when the flow has run down to a quantity hereafter to be determined.

136. *From Wells in the Lea Valley.*—Into this part of the case we have already gone very fully, and we need only repeat here that in very dry years the companies should not calculate on obtaining more than 40 million gallons a day.

137. *From the Chalk on the South Side of the Thames.*—From the existing wells of the Kent Company and others which may be sunk within their district we think that 27½ million gallons a day may safely be taken.

From the tract of Chalk country in the valley of the Medway and the larger area further eastwards to the coast a very considerable addition is also undoubtedly procurable.

138. The summary of the several quantities above stated is as follows:—

——	Millions of Gallons per Day.
From the River Thames - - - - -	300
From the River Lea - - - -	52½
From wells in the Lea Valley - - -	40
From wells in the Kent Company's district -	27½
Total - -	420

sufficient at 35 gallons per head per day for a population of 12,000,000.

Special Circumstances of Thames and Lea.

139. Before proceeding to consider the quality of the London water it will be well to point out that the drainage areas of the Thames and Lea differ materially from those drainage areas in the hill districts from which the large cities and towns in the north of England and in Scotland derive their water. A very large proportion of the drainage areas of the Thames and Lea consists of pervious land, through which the rainfall percolates, the water finding its way with a certain amount of natural filtration, and issuing in the shape of springs in or along the course of the rivers, many of the streams in the chalk districts being very rarely subject to floods. The water obtainable from the rivers in such drainage areas is, therefore, to a large extent freed from pollutions which may have previously affected it. Its admixture with large quantities of unpolluted river water, and the long distance of travel by the river, are also very important considerations to be taken into account when judging of the general character of the water which arrives at the intakes of the London water companies. It must also be remembered that the drainage areas are practically free from manufactures.

On the other hand, the supply of water to the inhabitants of the large northern towns is obtained by storing up in extensive reservoirs the floods from mountain drainage areas, in most cases very sparsely populated. Little of the rainfall percolates into the ground, but nearly all of it passes off in the shape of floods. These flood waters, after being stored in numerous reservoirs for settlement, are delivered to the inhabitants, in many cases without filtration.

There is therefore, a very marked difference between the condition of the water received from such drainage areas as the Thames and Lea, and that of the water which is supplied to the populous cities and towns in the north.

Quality of the Water supplied to London.

140. The quality of the London water in relation to the propagation of disease is a subject that may be examined either from the stand-point of theory or from that of experience, and it will be well to look at it from each point of view separately, so far as such separation is possible.

(1.) *Theoretical Considerations.*

141. Not many years ago it was the generally accepted doctrine among sanitarians that the question whether a given water was fit for consumption could be determined by ascertaining from chemical analysis in what proportion it contained organic matter; when there was much of this the water was unwholesome and likely to cause disease, when there was but little it could be drunk with impunity; and some analysts went so far as to lay down hard and fast lines of standard purity, on one side of which was danger, while on the other was safety. This position, however, soon proved untenable, and it had to be recognised that the wholesomeness or unwholesomeness of water depended, not on the quantity, but on the character of the organic matter it contained, and that not only was it possible, and indeed a frequent occurrence, that water containing very large amounts of organic matter could be drunk continuously by a population with perfect

impunity, but that water in which the organic constituents were so scantily represented as almost to defy chemical detection might, in spite of this apparent purity, prove to be of the most poisonous character.

The question, therefore, was one of quality of organic matter rather than of quantity. It is not, however, to be supposed that the question of quantity was of no importance whatsoever. Water derived from the ordinary sources that serve for drinking supplies contains, under normal conditions, only a very small proportion of organic matter, and the detection in it of a large amount is a reason for grave suspicion; for, though such matter may be perfectly innocuous, it is probable that the same channel by which innocuous organic matter has made its entrance may also serve for the introduction of less innocent materials, should such chance to be at hand. In the absence, therefore, of any better test, the condemnation of water as unfit for consumption that contained much organic matter was perfectly rational.

142. A considerable amount of evidence was brought before us as to the chemical constitution of the Thames and Lea water. No witness, however, founded upon this constitution any charge of unwholesomeness against the water as delivered to the London consumer; and consequently it is quite unnecessary for us to give in our Report any analysis of this purely chemical evidence. The only objection that can be made to the quality of the water on chemical grounds is that it is of such a degree of hardness as to render it less suitable for washing and for manufacturing purposes than would be a water of softer character. No evidence, however, on this subject was brought before us, and, as the question was thoroughly discussed in the report of the Duke of Richmond's Commission, we think it needless to say anything more about it.

143. The water question has, in fact, passed from the domain of chemistry into that of biology; for the next step in advance was the comparatively recent discovery that the matter, to the presence of which drinking water owed its occasional power of disseminating infectious diseases, was not merely organic matter, but living matter, consisting of certain microscopical vegetable organisms, known generally as microbes or bacteria, and divided by specialists according to their form into bacilli, spirilla, cocci, streptococci, and the like. These microbes are not only infinite in variety and number,
10,280, but are ubiquitous. The air we breathe, the food we swallow, the water we drink,
10,47–83 teem with them. They swarm within our own bodies, and this to such an extent
10,689. that it is said that six different species are invariably present inside the human mouth, while many other species are to be found there with more or less frequency. Fortunately the vast majority of these microbes are perfectly innocuous; many of them, indeed, are not only innocuous but serve useful or necessary purposes, for it is by them that the breaking-up of dead matter, animal or vegetable, and its reduction into inorganic substances is effected, and consequently by them that the purification of water or other media from foul organic matter is brought about. Many of them, moreover, act, as will be shown presently, as actual preventives of infectious disease.

144. There are, however, certain microbes that form exceptions to this general rule of innocuity, and that are capable of setting up more or less serious disease when introduced into the living body. These pathogenic microbes are given off from the bodies of animals or human beings already suffering from the special disease to which they respectively give rise; and, should they by any means find their way into the system of other animals or human beings that are capable of suffering from such disease, communicate to them the infection. That this is the manner in which infection spreads from individual to individual has been established beyond all possible doubt for some diseases, and it is believed from analogy that what has been ascertained for some infectious or contagious diseases is probably true for the whole class. Now, some of these pathogenic microbes, though their normal habitat is the living body, can maintain their existence for a longer or shorter period outside it, and can even multiply in water, or, if desiccated, can be carried, either themselves or their spores, in the air, and gain access to the body in the act of inspiration or otherwise.

145. Now, whenever there are aggregations of human beings living in the neighbourhood of rivers, and discharging their sewage into the stream, there is manifestly a possibility, or indeed a practical certainty, that some, at any rate, of the pathogenic bacteria given off by the sick members of such communities will find their way into the
7978. water, and it is consequently held by some persons, and has been strongly urged upon
12,885. the Commission by some of the witnesses that have appeared before it, that all water
3942. that has been liable to such contamination should be held as totally unfit for drinking
3987. purposes, and that no water should be deemed potable excepting such as has been

collected from uninhabited and uncultivated, and therefore unmanured, ground; for that water, when once polluted in the way described, will remain so for an indefinitely long period, and that no subsequent treatment by filtration or otherwise can be trusted to free it from the pathogenic organisms that have once got into it. 4195. 4677–8, 5008.

146. In reply to this argument it is said that, though it is undeniable that some of the infective substances given off by persons suffering from zymotic diseases may and do find their way into the rivers, the amount of such substances that thus enter the Thames and the Lea is extremely small, and indeed infinitesimal in proportion to the enormous bulk of water with which it is then mixed; that there are moreover numerous conditions which lead to the destruction or elimination of the pathogenic bacteria during the flow down the stream, and afterwards during the sojourn of the water in the subsidence tanks and during the process of filtration; so that it is extremely doubtful, to say the least, whether a single one of these pathogenic bacteria will remain in the water as delivered to the consumer, or even in the unfiltered river water itself; that in spite of frequent examinations none have ever been detected in it; and that, even on the improbable assumption that some few might exceptionally pass through the successive barriers to their entrance into the service pipes, they could not possibly be there in such number as to give rise to disease, which, according to all bacteriological researches, requires a certain quantity of such bacteria for its production. 10,083, 10,096, 10,101–3, 10,456–60, 10,660. 4250–2, 5021, 10,110, 10,722, 10,513. 10,315–6, 13,149–51.

147. Let us examine the evidence on which the successive allegations in this statement are based; and, in so doing, it will be best to confine ourselves, in the main, to that disease which, as will be hereafter seen, is, with the exception of Asiatic cholera, the only one which it is practically necessary to take into consideration, namely, enteric or typhoid fever.

148. The populations of the Thames and the Lea valleys above the intakes of the water companies are estimated as having been 1,056,415 and 189,287 respectively in the year 1891, while the areas over which they are spread consist of 3,548 square miles in the former case and of about 460 square miles in the latter. The populations are mainly agricultural, and, though there are a certain number of moderately sized towns, there are no large industrial or manufacturing centres, nor are there apparently the necessary conditions for such being developed hereafter. Areas such as these might be expected, *a priori*, to enjoy a more than average immunity from typhoid fever, and such natural expectation is confirmed by statistics. It appears from tables supplied to us by the General Register Office that the mortality from typhoid fever in those counties which practically form the water-basins of these rivers is, year after year, far lower than that of England and Wales as a whole; and the total annual number of deaths from this disease has varied during the 11 years, 1881–91, from 154 to 84 in the Thames basin, and from 30 to 19 in that of the Lea; and in each case the smallest numbers are those of the more recent years. It is usually reckoned that for every death from typhoid fever there are from six to seven attacks; so that, selecting in each case the year of highest mortality, we may estimate the total number of attacks as being 1,001 in the Thames valley above Molesey, and as being 195 in the Lea valley above Chingford. Let us suppose, though such is, of course, an impossible supposition, that all the discharges of all these cases pass directly into the rivers, and let us see to what extent they would, in that case, undergo dilution; and in so doing let us assume the worst possible combination, namely, that the years of greatest typhoid prevalence coincide with the years of smallest flow in the rivers. App. C. 41. 12,196. App. G. 4. 10,304.

149. The smallest annual flow in the Thames over Teddington Weir, after adding the water previously abstracted by the companies, in any one of the eleven years 1881–91, was in 1890, when the total volume amounted to 294,792 million gallons. The maximum estimated number of cases of typhoid fever in any one of these years in the Thames basin above Molesey, was, as already stated, 1,001. This would give one case of typhoid fever to, in round numbers, 294 million gallons of water, an amount which perhaps may be more readily apprehended if described as a mass 5 miles in length, 100 yards in width, and 6 feet in depth. A similar calculation made for the Lea gives for each typhoid case a body of water 3 miles in length, 100 yards in width, and 6 feet in depth.

In this calculation it has been assumed not only that the mortality was at its highest, and the river flow at its lowest, but that all the discharges of the infected persons passed directly into the river. This latter assumption is, of course, ridiculous; the amount that can be supposed actually to pass in cannot possibly be more than an excessively minute fraction of the whole. A very large proportion of the cases,

probably much the greater part, will have occurred in towns and places where there are sewage farms; and the discharges passed into the sewers, with or without disinfection, will then be applied to the land, by which, if not all, yet far the largest
4300, 10,082, part of the noxious substances will be retained. Even in the hamlets and the isolated
10,815. houses such application to land will be a very usual incident, for it appears to be the common and increasing practice of medical men to give strict instructions that all the dejecta of typhoid patients shall be buried in the garden, and not allowed to contaminate the midden. Still there will doubtlessly be from time to time cases where this proper precaution is neglected, and where the discharges are allowed to make their way without disinfection into the ordinary receptacle, which may possibly
3503, 4299, be a ditch or stagnant pool. Now it has been pointed out by more than one witness
4876–7. that, when a flood occurs, the contents of these ditches and pools will be washed down into the river, and the possibility of dangerous pollution from this source has been suggested to us.

150. That such an occurrence is possible, and, indeed, that it must occasionally happen, is beyond question. There are, however, several important considerations on the other side which must be taken into account before it is concluded that such an occurrence would constitute any appreciable danger. In the first place, the quantity of typhoid matter which could thus be washed down must be excessively small; and still smaller the amount of this which will have retained its power of setting up disease.

For it must not be supposed that typhoid dejecta retain their infectiveness for an
10,713. unlimited period. It appears to be the belief of bacteriologists that such dejecta
13,103. begin to lose their virulence after a very few days, and the longest period for which the typhoid bacillus has as yet been found to retain its vitality when in fæcal matter
13,109. does not exceed 15 days. One witness, it is true, told us that he has recently found reason for suspecting that the period might be prolonged to three weeks or more, when the fæcal matter was kept in the dark, and doubtlessly the present condition of bacteriological science does not allow of a precise statement of the possible period of survival. But in this, at any rate, all bacteriologists appear to agree, that the period during which the typhoid organism can maintain its vitality, when in fæcal matter, is very limited, and that both its virulence and its powers of multiplication are much enfeebled after but a few days. Nor can it be said that, though the typhoid
10,620, bacillus may itself perish, its spores may be, as is the case with many microbes, more
10,706–12, resistant, and may survive the death of their parents for an indefinite time, for the
10,854–6, bacillus to which typhoid fever is ascribed produces no spores. It is, therefore,
10,898, 13,116. only typhoid dejecta of very recent deposit from which danger is to be apprehended; and this clearly reduces very greatly the supposed risk of specific pollution of the water in time of floods. Secondly, it is manifest that in time of flood the volume of water will necessarily be enormously increased, and the dilution of such specific matter as may get into it will be at its maximum. A third consideration of some importance is this: the typhoid bacillus requires for its due development,
13,159. among other conditions, a somewhat high temperature, and though there may, of course, be floods at any time in the year, the most common season for them is in the colder months, and especially in January and February; that is to say, they occur preferentially, though not exclusively, at a season when typhoid fever is very rarely prevalent, and when such typhoid bacilli as may possibly get into the flood water have the smallest chances of successful development. Altogether we are led irresistibly to the conclusion, from the evidence put before us, that the amount of active specific typhoid poison that can get into the Thames or Lea, whether under ordinary conditions or in time of flood, is infinitesimally small when put into comparison with the enormous volume of water with which it will be diluted.

10,599, **151.** Before leaving this part of the subject it may be well to note that typhoid or
10,975. enteric fever is, so far as is known, an exclusively human affection, and can only be communicated to fresh individuals by means of the bowel discharges of a person already suffering from it; and that, consequently, the pollution of water by horse manure, or by the droppings of cattle, sheep, pigs, and other animals, however objectionable it may be on other grounds, cannot be regarded as a possible source of such disease.

152. The next question with which we have to deal is the alleged existence in rivers of numerous conditions which lead to the destruction or elimination of such pathogenic
13,135–7. microbes as may have found their way into them. The natural habitat of pathogenic bacteria is the interior of the living body; when they pass from this into the outer

air or water, they are in an unnatural medium, in which they can only maintain their existence and power of multiplication for a limited period, during which they undergo more or less rapid attenuation or loss of virulence, and become generally weakened. Meantime the ordinary water bacteria, by which, if in the river, they are surrounded in innumerable multitudes, being in their natural habitat, thrive and multiply, and become more and more likely to obtain the mastery in the struggle between themselves and their weakened pathogenic adversaries. For it appears to be the generally accepted doctrine of bacteriologists that the pathogenic organisms and the ordinary river bacteria, to which the decomposition of organic matter is due, are naturally antagonistic; and that these latter "undoubtedly exert an influence in diminishing the vitality of the typhoid bacillus," either actually consuming it or, as is more probable, giving rise to products that interfere with its growth. 13,138–40 13,123.

153. It is this antagonism of the non-pathogenic to the pathogenic bacteria, that supplies an explanation of the otherwise unintelligible fact, as to which all the bacteriological witnesses seem to agree, that pathological bacteria will live longer in distilled water or in water that has been previously sterilised, that is, from which all other bacteria have been removed, than in ordinary river water. It throws light also on the excessive mischief that ensues when the comparatively pure water of deep chalk wells, as at Caterham, has been accidentally fouled by specific infective matter. In the case of these deep wells there is moreover another condition, wanting in the rivers, that is favourable to the development of the pathogenic bacteria, being one of the conditions under which they grow in their natural habitat in the alimentary canal, namely, darkness. For it is found that while exposure to direct sunlight destroys these bacteria, even such a tempered amount of light as is present under ordinary conditions in Thames water injuriously affects their vitality. How important a germicidal influence is exercised by light is shown in the statement made by Dr. Sims Woodhead "that in the laboratory we are compelled to keep all our pure cultures, which are under favourable conditions of growth, in a dark cupboard; otherwise they would die out, rapidly becoming weaker and weaker. The same, of course, must be the case where, as in water under the open air, organisms are exposed to the light." 10,555, 10,833, 13,100. 13,212–4. App. C. 70.

We pass over the effects of diminished temperature in the water as compared with the living body, and of oxygenation, to come to another agency that perhaps more than any that have yet been mentioned tends to the elimination of pathogenic, and indeed of non-pathogenic, bacteria, namely, settlement. In river water there is always a more or less considerable amount of mud or other substances in suspension. When the water is at rest, as in a storage reservoir, this mud falls to the bottom as sediment, and carries with it a very large proportion of the bacteria that may be present. In experiments made by Dr. Percy Frankland, and Professor Ray Lankester with water to which finely powdered clay or other similar substances had been added, it was found that three-fourths, five-sixths, or even larger proportions of the bacteria, were precipitated; and in the valuable series of investigations made by the Massachusetts Committee the removal amounted to no less than 98 per cent., which also was the proportion of removals obtained by Dr. Percy Frankland by the addition of carbonate of lime as in Clark's process. 23rd Annual Report of the State Board of Health of Massachusetts.

Although this sedimentation is most complete when the water is at rest, as is, to a great extent, the case in the subsidence reservoirs of the companies, it is also going on constantly in a less degree in the flowing stream; and the process is here assisted by the constant change in the composition of the river water brought about by its successive affluents; for these changes in composition entail chemical action leading to continuous precipitations with every alteration of hardness.

A striking illustration of this process is furnished by the following interesting observation of Dr. E. Frankland:—"There is a peculiar action between the Thames water and the water of the Wey, which comes in a little way above the companies' intakes. . . . I made some experiments upon the effect of mixing these two waters together. The effect of mixing the Wey water with the Thames water is the production of a precipitate which contains a considerable quantity of organic matter. Hence, after the admission of the Wey to the Thames, although the Wey itself is not purer, or was not at that time purer than the Thames, the effect of mixing the two waters is to reduce the amount of organic matter in the mixture considerably below the mean of the two streams. There is a peculiar effect there of mixing the two waters. I cannot explain chemically what it is, but it results in the reduction of the organic matter." 4350.

154. So far we have considered the agencies that tend to the destruction or elimination of pathogenic bacteria during the passage of the water to the filtering beds. It remains to consider the action of the filters themselves.

The action of a filter-bed appears to be partly mechanical, partly vital; but the mechanical action, which is confined, or almost confined, to the holding back of the comparatively grosser substances suspended in the water, and which was supposed until recently to be the only operation in a filter, is now held to be of far less importance than the vital action, which depends on the activities of the gelatinous
12,634. layer of living matter gradually deposited on its surface. A new filter, composed
12,602. of perfectly purified sand, has little or no effect in producing either chemical or
12,626, bacteriological purification; but, in course of use, a layer charged with living
12,637. microbes is deposited upon the surface, and it is by these organisms which constantly increase in number, and also penetrate the sand to a slight distance, that both the nitrification of organic matter and the arrest of other microbes is
12,637, effected. Thus, the longer a filter has been in use the more efficient it becomes,
12,712. provided, of course, that the surface layer has not acquired such density as to interfere with the passage of the water; and consequently the recommendation, which was commonly given in former times, that a filter-bed should be cleansed as often as
12,603, possible, appears to have been a mistake; cleansing, by which the efficient superficial
12,636–8, membrane is removed, should only be carried out when the filter has become unduly
12,618. blocked.

155. The mode, however, in which the filters act, interesting though the subject be, is not at present so important to us as the extent to which they are efficacious in removing microbes from the water; and as to this we have not only the evidence of Dr. E. Frankland, but the series of interesting reports made by him monthly and annually to the Registrar General; and which now deal regularly with the bacteriological condition of the water before and after filtration. From these it appears that, as a
12,738. general rule, the filtration of water by the London companies is carried out efficiently; and that, when this is the case, from 98 to 99 per cent., or even a larger proportion, of the microbes are held back, and in some instances there has been even an entire
12,614. removal of microbes from the sample examined. Occasionally the efficiency falls far
12,592. short of this, and the water is delivered in an unsatisfactory condition; the explanation of such fallings off from the standard being the relaying of the filtering material in some of the beds and the consequent necessity of allowing the water to pass at far too rapid
12,597. a rate through such other filters as are still available for use. Putting these exceptional defects aside—which are to be met by increasing the number of filter-beds, so as to have
12,599. spare ones at command in time of emergency, or by having recourse to the method of double filtration—and assuming the water to be invariably as efficiently treated as it is usually by the most careful of the companies, the raw water of the Thames and Lea can
12,707–11. be transformed, in the judgment of Dr. E. Frankland—who, as well known, has been no sparing critic of the London water—into a beverage quite as good, from the point of view of health, as deep well water.

5150, 12,939, **156.** The occasional failure on the part of some of the companies to filter their water
12,951, in a thoroughly satisfactory degree is, of course, a defect for which remedy must be found,
12,981–4. and to this we shall revert later on. But supposing the filtration to be always as
4603. efficiently carried out as it might be, and as Dr. E. Frankland shows that it generally is, we are of opinion that the allegation which we have been examining, viz., that the various conditions and agencies that tend to the destruction or elimination of the pathogenic bacteria during the flow down the river, and afterwards during the sojourn in the subsidence tanks and the subsequent process of filtration, are such that it is extremely doubtful whether a single one of these bacteria will remain in the water, as delivered to the consumer—rests on a very substantial basis.

157. As regards the other arguments advanced in support of the wholesomeness of
Paragraph the London water, and briefly summarised at the beginning of this discussion, namely,
146. that, in spite of repeated examinations, no pathogenic bacteria have ever been discovered in the Thames or Lea water, even before filtration, and that, even on the improbable assumption that some few were present and succeeded in passing through the successive barriers to their entrance into the service pipes, they could not possibly be there in such numbers as to give rise to disease which requires a certain quantity of such bacteria for its production, we can only speak with some reserve.

It is certainly true that no pathogenic bacteria have yet been detected in the water of these rivers; but to this it is answered with much force, that the samples used in the

ordinary method of examination by plate culture are so excessively minute, that it cannot be inferred, from such want of detection in the sample, that the bacteria are really absent from the bulk. This objection is however met, at any rate to a considerable extent, by the experiments carried out by Professor Ray Lankester. In some 10,722–54. of these a considerable volume of raw river water was passed through a Pasteur-Chamberland filter, which, while it allows the water to percolate, holds back all the bacteria; while in others the substance for examination was obtained by taking some of the gelatinous layer of living microbes that had accumulated on the surface of a filter of one of the London water companies. The material obtained by these several processes from a relatively large bulk of water was then subjected to the most delicate of modern tests for the detection of typhoid bacilli, namely, that known as the method of Parrieti, and in no case was this bacillus found to be present. Experiments such as these, though they cannot be said to demonstrate the total absence of pathogenic bacteria from the river water before it enters the filter-beds, yet add largely to the probability of their being present, if at all, only in very small numbers.

158. There remains the question of the dose of bacilli required for the production of disease. "The general tendency of evidence," says Professor Odling, "is to show 10,122. that it wants a very considerable dose of a pathogenic organism to produce its characteristic disease." Similarly, Professor Ray Lankester says, "It appears probable 10,661. that any infection produced by these organisms must be by a certain volume—a certain number—that is to say, that one typhoid bacillus passing into, even arriving into the intestine, would not be able to hold its ground." Again, There can be little doubt," says Dr. Sims Woodhead in his statement, "that small App. C. 70. doses of the cholera bacillus introduced into the alimentary canal of a man or an animal are destroyed so rapidly by the secretions, or it may be by actual contact with the living cells of the stomach and intestine, that no symptoms are produced. In healthy individuals, however, a very large dose of the bacilli, with the accompanying poison, may alter the secretions, and paralyse the cells, so that the organism is enabled to grow in the nutrient medium contained in the alimentary canal, and an attack of cholera may result"; and he further states that he "is led to believe that the two organisms," that is, the microbes of typhoid fever and of cholera, "act in somewhat the same fashion as regards the infection of the human body." There is, however, he elsewhere states, not nearly so definite knowledge in 13,149. this matter as regards cholera and typhoid fever as there is in regard to anthrax and other diseases that can be inoculated directly into the tissues.

There appear then to be strong grounds for believing that small doses either of cholera or of typhoid poison may be swallowed with impunity; though it cannot be said positively that this is a fact beyond question. Dr. S. Woodhead has, however, urged upon us that some bacteria indisputably make their way through the filter-beds and that there is no positive certainty that among those that thus succeed in passing 13,145–6. there may not be a few pathogenic specimens; and that if even a single one of these gets into a cistern it may there multiply to such an extent as to be dangerous to all the persons in the house who consume the water. Provided we assume that the environment is suitable for the development of the typhoid bacillus and that the successive generations retain their normal virulence, the theoretical possibility of such an occurrence cannot we think be disputed. The real question is, however, not whether such an occurrence is theoretically possible, but whether it is sufficiently probable to bring it within the range of practical consideration; and that again is a question to which long experience of what actually happens can alone give a satisfactory answer, and what that answer is we shall see presently.

159. Such are the main features of the question when regarded from the standpoint of theory. Bacteriology, however, is still in its infancy; and, though the results obtained by experts in the science, in regard to the persistence or destructibility of pathogenic microbes, deserve full consideration as possessing a high degree of probability, it would be rash as yet to assign to them such a position of absolute certainty as would enable us to dispense with the evidence of experience. This must still be our main guide; and, consequently, we now proceed to consider what have been the results of experience, in regard to the wholesomeness or unwholesomeness of the water from the Thames and Lea rivers as delivered to the London consumers.

(2.) *The Evidence of Experience.*

160. There are only two infectious diseases in this climate of which it can be indisputably affirmed that they can be communicated from person to person by the agency of

drinking water. These are typhoid or enteric fever, which is constantly with us, and
3943–9, Asiatic cholera, which, luckily, is a rare visitor. It has, indeed, been suggested to us
4079. by sundry witnesses that other diseases, such as tuberculosis, erysipelas, scarlet fever,
4541–5. diphtheria, and small-pox might possibly be communicated through this channel; but
10,106–7. 10,597. no one of these witnesses could adduce any instance of the actual occurrence of
10,635. such communication, and, though innumerable outbreaks of these diseases have been
11,192–5. investigated by sanitary experts, in none have the facts apparently given rise to even a suspicion that the cause was to be found in the water supply, excepting, perhaps, in the case of diphtheria, concerning which one medical witness stated that he had
4900. had reasons on one occasion to suspect that such might have been the disseminating cause of an outbreak in his district. As it appears from the official mortality returns of the Registrar-General that diphtheria is specially frequent in London, and, moreover, that the mortality from this disease has increased in recent years, we have thought it desirable to obtain further information as to its possible connexion with the water supply, and with this object have had recourse to the official reports made by inspectors of the Local Government Board on outbreaks of this disease investigated by them. These reports are excessively numerous, but it will be sufficient to quote the terms in which their general result has been summed up by the present medical officer of the Board, Dr. Thorne Thorne. That gentleman thus expresses himself in the lectures delivered by him on diphtheria before the Royal College of Physicians (Milroy Lectures, London, 1891, p. 78–79). "I would say at once that no trustworthy evidence is forthcoming to show that polluted water supplies have ever caused diphtheria, whereas, on the other hand, there is an abundance of evidence in the opposite direction" (p. 78). And, again—"Dr. Airy, after considering the whole subject in his summary report of 1880, came to the conclusion that the disease 'did not appear to have any concern with the nature of the supply of drinking 'water,' and I may add to this statement that in no single instance out of the many investigations into the causes of diphtheria that have been made by the department of the Local Government Board since that date, has there been any reason to believe that water supplies polluted in one or another way have been concerned with disease" (p. 79).

161. Thus much, then, as to any supposed risk of the dissemination of diphtheria by
3974, 4079, water. But, as regards Asiatic cholera and enteric fever, the case is very different.
4544, 4724, All the medical witnesses who appeared before us stated unhesitatingly that both these
5074–6. 10,105, diseases could be, and often were, disseminated by water that had been specifically con-
10,597, taminated, and in so doing they appear to have expressed not only their own belief, but
10,635. the unanimously accepted opinion of all sanitary experts. Nor is it necessary to go beyond London itself, or its immediate neighbourhood, for examples of such occurrences.
10,694. As regards cholera, there is the well-known case of the outbreak in Golden Square and the adjoining streets in 1854, which was traced with a high degree of certainty to a well in Broad Street, which there was every reason to believe had been polluted by a closely adjoining sewer, into which it was known that cholera evacuations had been
4196–8. discharged. And as regards enteric fever, there is the equally well-known case of the
4570–3. outbreak at Caterham in 1879, which was traced to the direct pollution of the well,
10,694. from which the drinking water was supplied, by a workman, who, while suffering from the fever and from the profuse diarrhœa which attended it, was for the space of 14 days occupied inside the well on certain repairs.

Cases such as these and others which might be cited leave no reasonable doubt that drinking water can serve as the vehicle by which cholera and enteric fever are disseminated. The question, however, is not whether such dissemination is possible under any circumstances, but whether water, however slightly contaminated, can be freed from such contamination by proper precautions, such as adequate storage and filtration, or whether, as contended, it must be regarded as for ever unsuitable for drinking purposes.

162. The cases above quoted throw no light on this question. The conditions under which the water caused the outbreaks at Caterham and in Golden Square were utterly different from the conditions under which the water of the Thames and the Lea are distributed to the inhabitants of London. In neither of the two cases was the water filtered, and in neither was it the water of a huge river in which dilution would be at a maximum, but the water of a well, in one case of a small surface well, in the other of a deep well of considerably larger yield, but nevertheless of a yield that is utterly insignificant when compared with the volume of water that is brought down by the Thames and Lea. It appears from returns made by the Chairman of the

Caterham Water Company that the total amount of water pumped from the well in the 14 days during which it was being continually polluted, was 1,861,000 gallons. But if the volume of water brought down by the Thames to the intake be taken into account, and also the fact that at least 98 per cent. of the microbes in water are removed by filtration, it will be found on calculation that in order to produce an equal amount of pollution in the water supplied to the London consumer to that of the Caterham well, nearly half a million cases of typhoid fever must occur in a fortnight in the Thames Valley above the intake, the discharges from all these cases passing into the river as directly and in as great a proportion as did the discharges of the workman into the Caterham well, and no part of these discharges being arrested or destroyed on their way down to the Hampton intakes or during the sojourn in the subsidence tanks. But the entire population of the valley above Hampton consists—men, women, and children—of only about one million persons. Cf. 11th Report of L. G. B., Supplement, p. xx. 4403–6.

The outbreak, then, at Caterham, and still more the outbreak in Golden Square, afford no evidence as to the amount of risk, if any, attending the consumption of water from the Thames and Lea as delivered by the companies. Evidence must be sought elsewhere. With this view we have again had recourse to the official publications of the Local Government Board.

163. The reports made by the inspectors of the Board into the origin of outbreaks of enteric fever are very numerous, but the chief medical officer has been good enough to select from them such as appeared to him to be most apposite for the objects we had in view, and a list of those thus selected, with a short abstract of the chief conditions noted, is given in an appendix. An examination of these reports—21 in number—shows that in all the cases the water to which the outbreak of fever was attributed, App. F. with more or less certainty, was the water of a well, often a shallow well, or of a small rivulet or stream, or at any rate was water of small volume; that apparently in scarcely any instance was the water filtered, and that, when filtration of any kind was used, it is stated to have been inadequate. Such cases, therefore, however interesting they may be from other points of view, and however clearly they may demonstrate that water can serve as the vehicle for typhoid poison, throw no more light than the Golden Square and Caterham outbreaks upon the risks attending water delivered under the conditions that obtain in the case of London. There is, however, one outbreak that has recently occurred that appears to be more to the point.

164. In 1890 a serious outbreak of enteric fever occurred in the Tees Valley, and was attributed by Dr. Barry, the medical inspector, in a report published in the supplement to the Twentieth Annual Report of the Local Government Board, 1890–91, to the consumption of water taken from the Tees, and delivered after filtration by the Darlington Corporation and Stockton and Middlesbrough Water Board. This view he further upheld in a later and fuller report, which will appear in the supplement to the Twenty-first Annual Report of the Local Government Board, in continuation of the report of the medical officer for 1891, and of which we were favoured with advance copies; and in this final report he extended his inquiries to a second outbreak in the year 1891, and assigned to this also an origin in the Tees water-supply.

The conclusion at which Dr. Barry arrived in regard to the 1890 outbreak, to which we have more especially directed our attention, appears to have been mainly based on the following propositions:—

(*a.*) That the fever was so vastly more prevalent in the districts supplied with Tees water than in the districts supplied from other sources, that it may be said to have been practically confined to them. 13,915.

(*b.*) That the attacks were spread over all the districts supplied with Tees water with very great, though not, of course, with mathematically perfect, uniformity; and that the several districts were attacked simultaneously. 13,917–22. 13,916.

(*c.*) That, water-supply apart, there was no other difference of any importance between the Tees-drinking and the other districts. 13,923.

(*d.*) That there was an accumulation of filth upon the banks of the Tees at places above the intake, and notably at Barnard Castle, and that a flood, which happened on August 13th, 1890, must necessarily have washed this filth into the river; and that the time when the outbreak declared itself, after allowing for the incubation period, tallied with the view that the outbreak was caused by this pollution. 13,760.

This series of propositions doubtlessly constitutes a formidable indictment against the water-supply. They are, however, one and all traversed by Mr. Wilson, the App. C. 71.

representative of the Stockton and Middlesbrough Water Board, and the chief objections that can be made to them severally may be stated as follows:—

As regards the proposition lettered (*a*) it is admitted, speaking generally, that the fever was much more prevalent in the Tees-drinking than in the surrounding districts; but it is said that the difference in this respect between the two was very much smaller than represented by the inspector, inasmuch as notification
13,267–70. of cases was compulsory in the former with the exception of one sanitary district out of ten, while it was voluntary in the latter, with the exception of seven sanitary
13,962–88. districts out of twenty-two; and that in consequence of this the number of cases was largely overstated in the Tees-drinking districts, and largely understated in the other districts; and in support of this appeal is made to the respective case-mortalities, as deduced from the inspector's own tables.

13,391–400. To the proposition lettered (*b*.) it is answered that not only did numerous villages or
13,421. hamlets that were supplied with Tees water altogether escape, but that, in districts which were attacked, the attacks were not spread with uniformity over the area, but occurred, either exclusively or preferentially, in certain parts, and that this distribution coincided with marked difference in the sewerage arrangements, which were so faulty that previous outbreaks of fever had been attributed to them by official inspectors, and the probability of further outbreaks asserted.

To the proposition lettered (*c*.) it is answered that the water-supply does not constitute the only important difference between the two sets of districts; that the
14,052–82. Tees-drinking districts are almost exclusively urban, and the other districts almost
14,164–72. exclusively rural; and that if the 32 sanitary districts dealt with in Dr. Barry's report be divided into urban and rural, without regard to their water-supply, it is found that the reported fever cases were four or five times as numerous in the urban as in the rural group; and that the conditions of urban life, with its common sewerage and its closer aggregation of inhabitants, are notoriously more favourable to the diffusion of disease than are the conditions of rural life.

To the proposition lettered (*d*.) it is replied that, though the flood of August 13th must have washed down such filth as was on the banks, that filth can only have been such as had accumulated since the next preceding heavy flood, which was on July 1st; and that in this interval there had been no traceable case of enteric fever
13,925. in the area above the intake; and that consequently the filth cannot have contained
14,122. the specific poison which is essential for the production of enteric fever; and that the suggestion that there may have been cases of fever, unknown to the medical men, above the intake, is a perfectly unsupported hypothesis.

Dr. Barry, as we understand him, admits with some qualifications the truth of these criticisms, but maintains that, when all due allowance has been made for them,
13,914. there remains a body of evidence which they are not weighty enough to counterbalance, and which, though it does not actually demonstrate, constitutes a strong presumption, that the explanation of the outbreak adopted by him was the true one.

We felt strongly that without very minute and accurate acquaintance with the locality, and without much more elaborate knowledge of all the complicated circumstance of this and previous outbreaks of fever in the Tees Valley than it was practically possible for us to acquire, it was out of the question that we should decide between these conflicting opinions. Although, therefore, we have printed the evidence put before us concerning this outbreak, and have attempted to sum up as fairly as we could the main arguments on either side, we refrain from expressing any judgment as to its origin. This much, however, we may say; that the pollution on a given day of a river like the Tees, with a flow in time of flood of at least 1,000 million gallons in the 24 hours, by what must at most have been a very small amount of active enteric poison, at a point 17 miles above the intake, should so seriously affect the water that the admission of a certain limited amount of it into the reservoirs should produce, notwithstanding filtration, an extensive outbreak lasting for some
14,153. six weeks, is a hypothesis so startling, and so entirely unsupported by previous experience in other places, that it is fair to demand the most conclusive evidence before accepting it as proven; and, though we attach great importance to the opinion of such an experienced inspector as Dr. Barry, we cannot say that such conclusive evidence has in our opinion been brought before us.

165. After all, however, the main evidence on which we have to base our judgment is that furnished by London itself. For more than 30 years the inhabitants of London have been drinking water taken from the Lea and the Thames above Teddington at points either the same as those at which the present intakes are situated, or at points where the chances

of contamination were greater, and the population that has been thus supplied has varied from some two-and-a-half to five millions. Here, then, we have an experiment on a gigantic scale, largely exceeding in compass the aggregate experiences of all the other places in which outbreaks of fever have been subjected to inquiry, and an experiment moreover made under the very conditions, or at any rate under no more favourable conditions than those that are still in operation in London. What has been the practical issue of this prolonged and wide experience? Every medical 4576, 5100, witness that has appeared before us, whether his general feeling was favourable or 11,190, unfavourable to the water, has told us unhesitatingly that he knows of no single 11,224, instance in which the consumption of this water has caused disease. 12,573. This is the unanimous testimony of the medical officers of health, of the water analysts, and of the bacteriological experts, of all, in short, whose attention has of necessity been directed to the subject.

166. There is another method by which we can test the wholesomeness of the London water supply, so far as regards the production or dissemination of enteric fever. We can compare the mortality from this disease in London with that of other great towns. It appears from a table that has been brought before us by the medical officer of health to the London County Council, and which substantially agrees with App. C. 17. another supplied from the General Register Office, that, when such comparison is made, App. G. 1. Table II. the enteric mortality in London is found to be exceptionally low.

In the table prepared by the medical officer to the council, London is compared, in App. C. 17. regard to its enteric mortality, with 14 other great English towns "that have public "water supplies which are not excrementally polluted," and it is shown that in only four of these has the enteric mortality, on a basis of ten years, been slightly lower than in London, while not only has the mortality in the other ten exceeded that of London, but in four of the towns has been twice, or more than twice, as high. There appears, then, to be no reason whatsoever to believe that the water as delivered to the London consumer is in any degree chargeable with the production or dissemination of enteric fever.

167. It has, however, been pointed out by the medical officer of the County Council, while he admits that the test applied by him is "favourable to the wholesomeness of London water," that "the security afforded by existing arrangements can at present 5076. only be tested by the behaviour of enteric fever, and hitherto there has been no opportunity for estimating the value of these arrangements by the behaviour of cholera." This is, of course, perfectly true. The visitations of this country by cholera have happily been but few, and we have in consequence no experience concerning its dissemination comparable in amount to that which we possess in regard to enteric fever. So far, however, as there is any experience to guide us, there is no known instance in which a river fouled by cholera matter has, after a flow of some miles, caused disease among those who drank it below.

168. Dr. E. Frankland, who, independently of his wide acquaintance with all water questions, has had his attention specially directed to this subject as a member of the Rivers Pollution Commission, told us that he knew of no instance where the polluted water of a river, after storage and filtration, had produced cholera; and that he had searched so carefully that he felt assured that no such case existed. He 4265. was able, however, he went on to say, to cite one occasion, and only one, where a 4270. river water that had not been subjected to storage, and, possibly, not to filtration,* was supposed to have produced an outbreak, in a town 15 miles or more below the place where the stream had been polluted by cholera sewage. This town was Doncaster, and the outbreak, which occurred in 1866, and was supposed by Dr. E. Frankland to have declared itself some six or seven days after the first cholera discharge from Sheffield, the infected town above, had gone into the river, was thus described in a passage which Dr. E. Frankland quoted from the Sixth Report of the Rivers Pollution Commission.

"This town was supplied with water in 1866 from the Don, after the latter received the sewage of Sheffield and Rotherham. Sporadic cases of cholera occurred in Sheffield from the beginning of July to the end of October. In Doncaster a single death by cholera occurred in January, but the actual epidemic did not commence until July; it was most fatal in August and September, and it ceased on the 10th of November. Doncaster lost 36 persons by cholera, and 35 by diarrhœa," and the witness went on to state "that is all the information I could get about it at the time." 4272.

* It appears from the return to the House of Commons on Urban Water Supply, 3rd July, 1879 (No. 265), p. 118, that the water at the town in question was not filtered, even in 1879.

The circumstances of this outbreak, as described above, and which Dr. E. Frankland informed us were all that could be discovered at the time by the Rivers Pollution Commission, doubtlessly were such as to justify suspicion, and to call for further inquiry; but, in default of such further investigation, they appear to us utterly inadequate to support the contention, that the water was the cause of the outbreak; and an examination of the death register and the official report on cholera in 1866 has led us to the conclusion that, so far as any evidence can be obtained, the suggested explanation entirely breaks down; for the outbreak in Doncaster did not occur, as supposed by Dr. E. Frankland, six or seven days after the first pollution by cholera sewage of the river at Sheffield, nor, as described by the Rivers Pollution Commission, in the month of August—there having been only one cholera death in that month, and that on the very last day of the month—but in September, and mainly in the third week of that month; and the 29 deaths that occurred from September 6th to October 3rd were not scattered over the town in the way that would have been the case had the common water supply been the originating cause, but were almost exclusively confined to an excessively limited area, 22 out of the 29 having occurred in a little group of 11 almost contiguous houses in Robinson Row and St. Anne's Square, while two others, that occurred in the hospital, and were registered without statement of the place of residence, may very possibly have been admitted from the same locality.

Cf. Registrar General's Supplemental Report on Cholera Epidemic of 1866, p. 237.

Cf. Reg. Gen. Report on Cholera, 1849–50, p. lvi.

169. It may, moreover, be noticed that the general rule that has been observed as to the spread of cholera over the country has not been that it makes its way down the rivers, but that it travels in the contrary direction, which is manifestly incompatible with the hypothesis that it is by means of the water supply that the infection is usually carried from one town to another. That the infection should travel in an inland direction is perfectly intelligible when it is borne in mind that cholera comes to us from abroad, and that consequently it is in the seaports and near the mouths of rivers that almost invariably it first declares itself. It is, therefore, the inland towns on the Thames and Lea that have reason to dread being infected from London, rather than London that has to be apprehensive of infection from them.

170. Again, there is reason to believe that if the typhoid bacilli are unable to pass through the various barriers, physical and vital, that impede their entrance into the service pipes of London, the microbes to which most authorities ascribe Asiatic cholera are still less likely to be able to do so. For, independently of the fact that they are described as thicker in diameter than the typhoid bacillus, they are stated by Messrs. P. Frankland and Marshall Ward in their report to the Royal Society, of which copies have been supplied to us, to be much more easily destroyed, being, in fact, very delicate organisms that, in the words of Dr. S. Woodhead, "cannot brook the presence of vulgar bacteria"; Dr. E. Frankland also stated to us that the result of experiment was to show that the cholera bacillus is soon destroyed in river water, where there are many competing microbes, and that in all probability water passing any considerable distance down a river would lose them.

4924, 5078, 10,583.

4549–55.

171. Doubtless, these bacteriological questions are not matters concerning which it would become us to make positive and dogmatical assertion, seeing that at present experts in the science of bacteriology are themselves avowedly holding their judgment in suspense. This much, however, we can state without hesitation, that, as regards the diseases in question, which are the only ones known to be disseminated by water, there is no evidence that the water supplied to the consumers in London by the companies is not perfectly wholesome. In coming to this conclusion we are glad to find ourselves in full accord with the opinion expressed, with equal conviction, by the Water Commission presided over by the Duke of Richmond in 1869.

Before leaving this subject, however, it will be well for us to apply the test of experience to the suggestion mentioned in an earlier paragraph, that a few typhoid bacilli, or even a single one, might possibly pass through the filter beds and, getting access to a domestic cistern, might there multiply to such an extent as to cause an outbreak of disease, limited to the household using that cistern.

Paragraph 158.

We shall, we believe, be well within the mark in estimating the number of household cisterns in use in London to have averaged at least half a million during the past 20 years. Day by day water for drinking purposes has been drawn from each of these cisterns, and a fresh supply admitted from the mains, so that it is no exaggeration to say, that there have been in the last 20 years thousands of millions of opportunities offered for the suggested catastrophe; and yet not a single instance can be adduced in which it has actually occurred. It may, of course, be said that such a thing may have happened without detection, and it is impossible to prove that such may not have

been the case; but, seeing what innumerable opportunities there have been for the occurrence, the absence of a single demonstrated case forms so strong a presumption against its practical possibility, that it may in our opinion be dismissed from consideration.

In this connexion we would call attention to the following extract from the evidence given by Dr. Dudfield, a medical officer of health of long standing, who has specially directed his attention to the subject of cisterns:—*Q.* "Did you ever hear of any case 11,224.
where there could be disease of any kind traced to this water?"—*A.* "No. I have been a careful observer of this matter for 20 years; . . . . and I have never been able to trace any connexion whatever between the water supply and disease, so far as the companies are concerned. But many times I have had occasion to suspect the water as a means of conveying disease when the cistern has been in direct communication with the drain or sewer by means of an untrapped water pipe. Such cases were very common in bygone years, and one of our principal duties has been to see to the removal of waste pipes. . . . . But I say, in those cases where the water has been suspected to be the source of disease, such as typhoid fever, it has been by contamination locally, through the agency of the waste pipes." *Q.* "And not through 11,225.
the supply?"—*A.* "Not through the supply. I say deliberately that I have never traced any disease, or had reason to suspect the occurrence of any disease, as due to the water as it comes from the mains." *Q.* "And your experience enables you to 11,226.
speak with some authority on that subject?"—*A.* "I speak with complete confidence. From the very first year of my appointment I made it a very special study, and I have never ceased to study the question, and to make observations to the best of my ability."

Recommendations.

(1.) *As to the Prevention of Pollution.*

172. In order to preserve the wholesomeness of the water as delivered to the consumer and in order further to meet the not unnatural sentiment against drinking water, which, though wholesome, has been polluted at an earlier stage, all possible vigilance should be exercised to prevent unnecessary contamination of the Thames and Lea and their respective tributaries, to ensure the thorough treatment of all sewage, before it is allowed to pass into the rivers, by the most efficacious methods that science and experience may dictate, and to enforce the adequate storage and filtration of such water as is abstracted at the intakes.

There can be no possible doubt that at the present time much filth of various kinds is discharged unnecessarily and illegally into the rivers, and steps should be forthwith taken to put an end to this. The London County Council engaged three medical officers of health to inspect personally the whole course of the Thames and Lea and their tributaries, and to report in detail as to all the sources of pollution they might detect. These three gentlemen Apps. C. 10,
appeared before us as witnesses, and handed in complete lists of the pollutions observed 11, 12.
by them during their inspection, and these lists are printed in an appendix to the evidence. The pollutions mentioned are very numerous, as might naturally be expected, seeing that all that were detected, however trivial they might be, were entered in the 3936.
account, and that, including the tributaries, many hundreds of miles of watercourse must have been examined. The point, however, to which we especially wish to direct attention is that in a very large proportion of the cases the pollution recorded was preventable and illegal, being in direct contravention of the Rivers Pollution Prevention Act, of which one of these witnesses stated that "all through the country I think 3963.
the Rivers Pollution Prevention Act has been more or less a dead letter. I do not think it has been put in force in many instances."

Some advances have, however, been made during the past 25 years in the construction of sewage works in the valleys of the Thames and Lea. Where such works have been constructed on an efficient system, the sewage can be so effectually dealt with at all times, except those of flood, that the effluents are clear and innocuous. We understand that in some of the places which still require sewage farms, or works for the efficient treatment of sewage, operations are already in progress for providing them; and we are of opinion that in the rest steps for the attainment of the same object should be taken without delay. We are aware that all sewage farms and sewage works are liable through carelessness or accident to do their work at times with less than proper efficiency. For the purpose of keeping them up to a sufficient standard, frequent inspection by an authority appointed for the purpose is, in our opinion, absolutely necessary.

5706–10. 6247. **173.** In the Thames basin, not only the river conservancy but the county councils and the sanitary authorities have the power of putting the Rivers Pollution Prevention Act in operation. The sanitary authorities, however, speaking generally, do not appear to consider such action to be any part of their duty, unless the
3958–63. pollution be such as to affect the health of their own limited district, and both sanitary authorities and county councils have hitherto practically left the matter
5709. to the conservancy, the councils, as one of their chairmen told us, "being very desirous to avoid anything like friction with a body which has concurrent jurisdiction with ourselves," and the sanitary authorities pleading that "the Thames
5710. Conservancy are paid for doing a great deal of this work." Some of the county councils appear, however, to recognise their obligation, for the chairman of the
5739. Sanitary Committee of the Surrey Council informed us that "they hold it distinctly to be their duty to carry out the provisions of the Rivers Pollution Act, ... and that you may rely that Surrey will take up that work, and that it will have the full support, certainly of Middlesex and London, and probably of every county council in the district, in keeping the river as pure as it is now, and, I should hope, much purer."

39 & 40 Vict. c. 75. 5704. It appears that in the Lea Valley the only body upon which devolves the duty of seeing that this Act is enforced is the Lea Conservancy Board, to which this power is given exclusively by the ninth section of the Rivers Pollution Prevention Act, 1878.

174. As regards the Thames Conservancy Board, its effectual action is hindered by
3377. several causes. In the first place its jurisdiction over the tributary streams is limited to a distance of 10 miles from the main river, so that any pollution may occur
3373. higher up with perfect impunity. Secondly, it is evident that no really satisfactory supervision can be exercised over several hundred miles of waterway without a considerable staff of inspectors, and the staff which the conservancy at present maintains, and which consists of two chief inspectors, two assistant inspectors, and four river-
3378, 6120. keepers, appears to us to be utterly inadequate for the purpose, especially when it is borne in mind that these officials have other duties to perform besides that of inspection. The small size of the inspecting staff appears not to be due to any
3534, 6158. unwillingness on the part of the conservancy to perform their duty, but to the limited funds at their disposal. A third hindrance to the effectual action of the conservancy is caused by the very cumbrous procedure they have to adopt when they
6327. come to deal with a recalcitrant offender. It is true that the procedure under the
6324–7. Conservancy Acts is not so cumbrous as under the Rivers Pollution Prevention Act, still even under these it appears that, when a pollution has been discovered, 12 months' notice must be given before any further steps can be taken, and that even then the difficulties and delays are by no means exhausted. Such abatements of pollution as the Conservancy have been able to obtain have been rather by gentle
6326. persuasion than by legal proceedings, but "they believed that if the Acts were simplified, and the action of them made more expeditious, they could entirely stop
6327. the pollutions throughout the whole district."

In this expression of opinion on the part of the Conservancy Board, as also in their further suggestion that their powers should not be limited to a distance of 10 miles from the main river, but should be extended to the whole course of the tributaries, and that it should be made an offence to pollute a tributary, we fully concur; while we would add the further recommendation, already mentioned by us, that the staff engaged in inspection should be very considerably increased, the necessary funds for this purpose being provided by the water companies, or such other bodies as are permitted to take water from the rivers; and, though in the above remarks we have specially referred to the Thames, we intend our recommendations to apply equally to the Lea and its tributaries.

1264–72, 1524, 1551, 6907–66, 7038–108, 7109–42, 6823–6906, 6967–7037. App. H. 1. Sub-app. N. **175.** Reference is made to the sewage of Hertford and to the state of the Manifold Ditch in the evidence of Major Lamorock Flower and Mr. W. C. Young, of Messrs. Longmore, U. A. Smith, and Cramp, and of Drs. Stevenson and Turner, and the result of inquiries and visits by our Assistant Commissioner will be found in his report. Some of our number have also visited the locality and inspected the sewage works; and we are of opinion that the state of matters now existing ought to be remedied without delay. To effect this it will be necessary to strengthen the hands of whatever authority may be entrusted in future with the prevention of such pollutions.

1218, 4755, 4791–4. App. H. 1. Sub-app. R. Our attention has also been called to the traffic in gas-lime, manure, and town-refuse which exists upon the Lea as far, at any rate, as Hertford. Large heaps of such matter are placed on the edges of the banks and within a few feet of the stream

itself. It is obvious that in times of rain and flood they become a source of pollution which is quite unnecessary and might be easily avoided by the exercise of a little care and foresight. We recommend that no collections of manure and refuse should be allowed within a certain specified distance of the river, or of any side stream or tributary, and that the duty be imposed upon some authority of seeing that this prohibition is enforced.

(2.) *As to the Treatment of the Water after Abstraction from the River.*

176. We have further to consider what steps should be taken to ensure the proper treatment of the water that is taken from these rivers for the supply of London. For the water that flows down to the intakes must be subjected to certain important processes before it is brought into a suitable condition for delivery and consumption. These processes consist of subsidence and filtration, and the quality of the water when delivered depends largely upon the thoroughness with which they are carried out. It does not come within the terms of our reference to lay down what should be the exact regulations as regards filtration, that is to say, what should be the proportionate area of the filtering beds, the depth of sand, the frequency of renewal, or the rate at which the water should be allowed to percolate; nor, as regards the subsidence tanks, how many days' storage should be deemed sufficient so as to obviate the necessity of taking in turbid storm water, and to allow of due settlement; but we cannot shut our eyes to the fact that the provision for these purposes differs enormously in the different companies, and in some of them is to our mind quite inadequate. See Table, paragraph 61.

177. Regulations on these matters should be drawn up after competent inquiry, and adherence to these regulations should be strictly enforced. This enforcement should be entrusted to the public water examiner, who should have the legal right of entry into all the waterworks, and the duty of reporting periodically as to the due observance of the conditions laid down. At present the examiner is only admitted to the works 13,055-6.
on sufferance, and, though he has distinctly informed us that he has always been admitted not only without hesitation but with all courtesy by the various companies, it is plain that the standing ground of a man who is inspecting by right is very different from that of one who is only present by courtesy.

CONCLUSIONS AS TO QUANTITY AND QUALITY.

178. We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of excellence and of purity, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and the Lea, because these rivers are liable to pollution, however perfect the subsequent purification either by natural or artificial means may be; but having regard to the experience of London during the last 30 years, and to the evidence given to us on the subject, we do not believe that any danger exists of the spread of disease by the use of this water, provided that there is adequate storage, and that the water is efficiently filtered before delivery to the consumers.

179. With respect to the quantity of water which can be obtained within the watersheds of the Thames and the Lea, we are of opinion that, if the proposals we have recommended are adopted, a sufficient supply to meet the wants of the metropolis for a long time to come may be found without any prejudice to the claims, or material injury to the interests, of any districts outside the area of Greater London.

180. We are of opinion that an average daily supply of 40 millions of gallons can be obtained from wells and springs in the chalk of the Lea Valley without affecting any material interests; but that, if that quantity is exceeded, it is probable that the springs and wells in the parts of the valley immediately adjacent to the wells, and all the districts further down the valley may be injuriously affected.

From wells in the chalk area on the south side of the Thames, in the district of the Kent Company, we are of opinion that a daily average supply of 27½ millions of gallons may be obtained.

We think it of very great importance that distinct obligations should be laid upon any Company or local authority which is allowed to pump water from the chalk for purposes of public supply, to keep accurate observation of the effect of their operations on the level of the water in the wells from which they pump, and return the

results to the water examiner under such regulations as may be framed. The great difficulty which we have had to encounter has been in getting accurate and reliable information as to the actual effect of the operations now carried on. The importance of procuring this will increase each year as the limit of what can be taken from any district with safety is gradually being reached.

181. From the River Lea we are of opinion that, with adequate additions to the present system of storage, 52½ millions of gallons may be taken daily.

182. We are of opinion that by the construction of storage reservoirs in the Thames Valley, at no great distance above the intakes of the companies, it will be possible to obtain an average daily supply of 300 millions of gallons without taking in any objectionable part of the flood-water.

The average daily flow of the Thames at Teddington Weir, adding the water taken by the companies, is about 1,350 millions of gallons per day. It will thus be seen that, when 300 millions of gallons are taken, there will be left to flow down into the tidal portion of the river an average daily quantity of not less than 1,000 millions of gallons; and we think that regulations could be framed under which the quantity we suggest could be taken not only without reducing the flow of the river on the rare occasions of exceptional drought to the present minimum, but in such a way as to secure that the volume of water left in the river at these times would be substantially greater than it is under existing conditions.

To our minds one great advantage of such a scheme of storage reservoirs is that it can be carried out progressively to meet the increasing demands for water, and, should the population not grow so rapidly as we have thought it right to contemplate, the extensions may be from time to time deferred as successive decennial enumerations reveal that the ratio of increase is remaining stationary, or even falling.

183. From the sources and by the methods we have mentioned a daily supply of 420,000,000 gallons can, in our opinion, be obtained. This is a sufficient quantity to supply 35 gallons a head to a population of 12,000,000 persons, which is about three-quarters of a million in excess of what the total population of Greater London together with the outlying parts of Water London will have become in 1931 even if the ratio of increase in the decennial period from 1881 to 1891 is fully maintained.

184. We are further of opinion that a large supply of water might be obtained from the chalk area east of the Kent Company's district, in the basin of the Medway, and in the district further east without any risk whatever of damage to that area.

All which we humbly submit to Your Majesty's gracious consideration.

BALFOUR OF BURLEIGH, *Chairman.*
GEORGE B. BRUCE.
ARCH. GEIKIE.
JAMES DEWAR.
GEORGE H. HILL.
JAS. MANSERGH.
WILLIAM OGLE.

FRANCIS GASKELL, *Secretary,*
September 8th, 1893.